DecisionTogether©: Integrating Life Cycle Assessment and Multicriteria Decision Analysis to Engage Diverse Stakeholders in Environmental Decision-making

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DEDICATION

To Team Gardiner: Jay, Jackson, and Ali
Together we can do so much. Without your love and support, I could never push myself and go as far.

To Mom and Dad: Thank you for your love and support for every crazy idea I have thought up. From softball to a Ph.D. to beyond!

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CHAPTER I

Introduction

Overview

Sustainable environmental decision-making can often be challenging. The process involves multiple criteria, uncertainties, and in some cases, multiple decision-makers or stakeholders. Finding consensus with a diverse group of stakeholders is difficult, and often outcomes are difficult to understand, utilize, or implement. This concept is true when stakeholders attempt to make decisions related to selecting a preferred environmental alternative when environmental impact is overshadowed by other criteria, such as economics and social concerns. However, the sustainable development model has grown to encompass the economic, environmental, and social attributes of a system. This simplified model considers all three attributes of equal concern. Yet, there are trade-offs between these attributes, which are not comparable in a linear way. Often economics dominates environmental and social concerns during evaluations of sustainable systems (Giddings, Hopwood, & O'Brien, 2002). To allow for guided evaluations of sustainable systems, there needs to be a methodological decision framework to help define the boundaries of the evaluated system, to identify sustainable alternatives for evaluation based on appropriate criteria and attributes, to provide an understandable means to evaluate and compare elements, and to allow for the engagement of diverse stakeholders.

During environmental system planning, decisions are often made based on current knowledge and perspective, sometimes with limited or preliminary data. A decision-making framework can integrate these elements to allow stakeholders to develop consensus or disagreement to aid in establishing a path forward. Convergence of four, dependant aspects must occur to make sustainable decision making useful and operational: (1) science and technology must exist to support the concept, (2) policies and regulatory frameworks must be well-formulated, (3) businesses should be actively involved, and (4) public stakeholders must understand and support it by incorporating their voices in the process and showing the results in understandable interactive manner (Halog & Manik, 2011).

This research develops a methodological decision-making framework that integrates conceptual environmental systems evaluation with an interface to engage diverse stakeholder groups. The decision-making framework is used to evaluate the trade-offs between pertinent criteria, such as environmental, economic, social, to aid stakeholders' consensus of environmental systems. While the decision-making framework is scalable and generalized for applications to evaluate different environmental systems, the decision-making framework is applied to assess future end of life systems for municipal solid waste (MSW) management systems for Middle Tennessee. The goal is to aid diverse stakeholders in the evaluation of criteria and alternatives to establish preferences and to consider areas of consensus to inform future planning and policy development.

Research Objectives

The research objectives for this dissertation include:

- How can Life Cycle Assessment (LCA) be utilized to inform decision-making?
    - Is LCA a useful tool for framing environmental decisions?
    - What is the best approach to integrate LCA with existing Multicriteria Decision Making Analysis (MCDA) methods to achieve consensus in environmental decision-making in the case of diverse stakeholders?

- How can Streamlined Life Cycle Assessment (SLCA) be used to inform decision-making?
    - Can SLCA be used as a means to simplify system boundaries for integration with MCDA methods?
    - How does SLCA compare to LCA in the definition of environmental systems and evaluation of energy and environmental impacts?
    - What is the best approach to integrate SLCA with existing MCDA methods to achieve consensus in environmental decision-making in the case of diverse stakeholders?
- How can the integrated SLCA and Analytical Hierarchy Process (AHP) methodology be used to elicit input from diverse stakeholders?
    - Can the integrated methodology be applied for the evaluation of end of life Municipal Solid Waste (MSW) systems?
    - How does stakeholder consistency compare with their perception of their prioritization of environmental, economic, social factors, and technical factors when comparing end of life MSW management systems alternatives?

The first objective focuses on the LCA and how it can be utilized in the evaluation of environmental decisions. LCA is applied to evaluating end of life MSW systems for Metro Nashville. The research evaluates how LCA can be integrated with MCDA methods to evaluate the criteria and alternatives framed by LCA to prioritize criteria and alternatives.

The second objective involves the evaluation of SLCA for the planning stages of environmental system evaluation SLCA streamline the LCA process through simplification of boundaries, inputs, outputs, and environmental criteria. This research evaluates SLCA's ability for integration with MCDA.

The third objective will evaluate how SLCA and the MCDA methodology, AHP, can be integrated to evaluate preliminary environmental systems through the engagement of diverse stakeholders and applied to evaluate end of life MSW systems for Metro Nashville. Stakeholder consistency in completing the AHP pairwise comparisons will be evaluated using mathematical formula and control charts to evaluate how data interpretation and stakeholder perceptions are useful in evaluating the prioritization of criteria, attributes, and alternatives.

Dissertation Organization

This dissertation is organized to address the objectives listed in the previous section. Chapter II is an overview of background information providing the fundamentals of LCA and MCDA methods, including AHP and decision-making. The application of LCA and SLCA for end of life MSW systems is discussed in Chapter III. SLCA is evaluated for its ability to be used as a surrogate for LCA in the early stages of decision-making. Chapter VI discusses how diverse stakeholders can be engaged in the decision-making process and presents DecisionTogether©, the integration of SLCA and AHP. The application of DecisionTogether© to evaluate end of life MSW systems for Metro Nashville is presented in Chapter V. Additionally, the chapter discusses the development of criteria, attribute, and scenarios, the stakeholders' engagement process, and the elicitation results. Chapter VI concludes the dissertation and offers ideas for future work.

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CHAPTER II

Literature Review

Background

Life Cycle Assessment (LCA) is a scientific approach used to evaluate the emissions and resources consumed by a specific product system or operation outlined by ISO 14040:2006 - Environmental management -- Life cycle assessment-- Principles and framework[1]. ISO 14040:2006 describes the principles and framework for LCA including definition of the goal and scope of the LCA, the life cycle inventory (LCI) analysis phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, the reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements. It does not describe the LCA technique in detail, nor does it specify methodologies for the individual phases of the LCA. The intended application of LCA or LCI results is considered during the definition of the goal and scope, but the application itself is outside the scope of the International Standard.

The LCA is the result of increased awareness on the importance of environmental protection and was developed to perform an impact assessment regarding three main areas of protection: human health, natural environment, and issues related to natural resource use (Joint Research Centre - European Commission, 2011). This process thoroughly looks at all system inputs and outputs, through clear system boundary definition, from cradle-to-grave (raw material extraction to final disposal after useful life has ended), but system boundaries can be truncated to represent gate-to-grave allowing for simplification of the scope. Associated LCAs for processes

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[1] Technical Committee : ISO/TC 207/SC 5 Life cycle assessment

and materials which feed into the life cycle stages can be considered. Energy consumption can also be evaluated through LCA for primary and secondary processes. LCA has evaluated the environmental impacts of product design, waste management, greenhouse issues, biofuels, and water management (Horne, 2009).

The comprehensive nature of LCA can be costly due to necessary databases and software packages and time-consuming based on system development and data collection. Environmental practitioners have questioned whether the LCA process goes beyond the capabilities of most potential users and if it is relevant to the decision-making process. This has encouraged some practitioners to examine methods of streamlining the LCA process, making it more accessible and usable, without losing the essence of the ISO standard. Additionally, LCA results may not be straight forward to understand because of differences in units and orders of magnitude (Zanghelini, Cherubini, Ao, & Soares, 2018).

The LCA process cannot comprehensively rank the environmental impacts and does not provide an easy way to integrate the results into a decision-making process (Tsang, Bates, Madison, & Linkov, 2014). To improve LCA's effectiveness for environmental systems planning, LCA needs to be integrated with a complimentary decision-making process. The environmental and energy results from the LCA process provide the framework to consider additional criteria important in stakeholder decision making. Integrating LCA with a decision-making methodology such as Multicriteria Decision Analysis (MCDA) provides the ability to frame and evaluate LCA results in parallel with additional criteria of interest (Linkov & Seager, 2011; Zanghelini et al., 2018). The traditional approach to environmental decision-making involves valuing multiple criteria based on a common unit, usually monetary (Kiker et al., 2005). Yet, independence is lost when environmental impacts are converted into economic metrics.

Therefore, a new methodology needs to be considered for the integration of LCA and decision-making.

Stakeholder participation is essential to providing comprehensive environmental system evaluation. Stakeholders have varying objectives and experiences they rely on when participating in evaluations. Research shows that stakeholder participation can enhance the quality of environmental decisions. Additional factors that improve environmental decision-making include more comprehensive information on inputs and taking into account the early stages of decision-making can inform the design of the decision framework with regional ideas and perspectives (Dougill et al., 2006)

Life Cycle Assessment Methodologies

The three LCA methodologies and simplifications are identified for use in environmental systems evaluation, based on increasing rigorousness and quality and quantity of information used to support the system developed and the decision (Wenzel, 1998). They include:

- *Screening LCA* – This level includes qualitative information used in the early stages of a product or system evaluation when limited information is available for the development of the LCA.
- *Streamlined LCA* (SLCA) – During data collection, it is not always possible to quantify the data used in evaluation (Hochschorner & Finnveden, 2003). This level includes both quantitative and qualitative information evaluation based on readily accessible databases and expert knowledge and is not intended to develop new data calculations.

- *Full LCA* – This level includes quantitative information, new data inventory collection, and calculation utilizing a computer.

The selection of the proper LCA method is based on the type of decision the LCA developer intends to propose, as discussed below.

Full Life Cycle Assessment

Full LCA is defined as the "compilation and evaluation of inputs, outputs, and the potential environmental impacts of a product system through its life cycle" (International Organization for Standards, 2006). "Product" is used broadly in LCA and can include physical goods as well as processes and services (Guinée, 2002). As discussed previously, Full LCA examines product life cycles from cradle to grave analyzing the environmental burden of the product at all stages of its life cycle, such as extraction of resources, transportation of materials, and energy production for use in the product system, emission of hazardous substances, and different types of land uses (Vigon, 1993). LCA is a quantitative approach that can also have qualitative elements that are used to complete the environmental picture being evaluated (Guinée 2002). The qualitative approach relates using to data that can be measured and quantified with a high degree of certainty, while the quantitative approach involves data that may be imprecise but provides the ability for comparison of magnitude ("Life Cycle Terminology – Life Cycle Initiative," n.d.).

As shown in Figure 1, the four distinct phases of a Full LCA include:

1. Goal and scope definition,
2. LCI Analysis,
3. LCIA, and
4. Interpretation (Guinée, 2002).

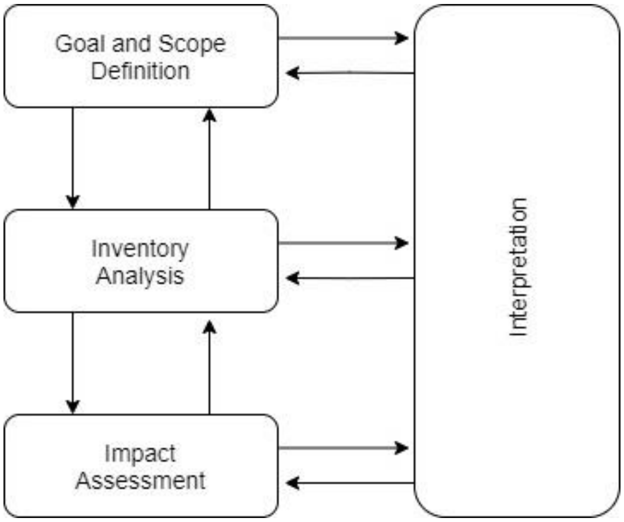

Figure 1: Stages of the Life Cycle Assessment

The Full LCA process has been adapted from the product system and simple services evaluations to evaluate complex business strategies and government policies relating to consumption and lifestyle choices, for example:

Evaluating the choice of one-way packaging by an industry:

- Comparing different types of waste management by a municipality or the development of a waste management strategy;
- Assessing the environmental benefits of different types of biomass use, for instance in the production of electricity or paper;

- Performing strategic comparison between different modes of freight transport as a basis for public investment in new infrastructure;
- Evaluating environmental burdens imposed by all building materials of a house (Guinée, 2001).

Goal and Scope Definition

The goal and scope phase clearly defines the system that is consistent with the intended application of the study. The goal states the intended application, reason, and the audience for the study. The scope may be refined as needed during the Full LCA process Aspects to consider during the goal and scope phase include:

- The scope of the study that should be considered;
- The product system being studied;
- The function of the product system, or in the case of comparative studies, the systems;
- The functional unit;
- The system boundary;
- Allocation procedures;
- Life Cycle Impact Assessment (LCIA) methodology and types of impacts;
- Interpretation to be used;
- Data and data quality requirements;
- Assumptions;
- Limitations; and
- Value choices and optional elements. (International Organization for Standards, 2006)

The functional unit is defined during this phase to normalized and compared all results on a similar scale. It should be clearly defined and measurable to provide a reference to how the input and output data are normalized. For example, all emissions are based on weight or product produced to allow for a comparison of impacts across the entire product system. The system boundary determines which unit processes and level of detail required for the study. The deletion of life cycle stages, processes, and inputs and outputs are only permitted if the modification does not significantly change the overall conclusion of the study and are documented and justified. Use of a process flow diagram is helpful in presenting the unit processes and their interrelationships. Each process should define:

- Where the unit process begins, in terms of receipt of raw material or intermediate products;
- The nature of the transformations and operations that occur as part of the unit processes, and
- Where the unit process ends, in terms of the destination of the intermediate or final product (International Organization for Standards, 2006).

The product system should be modeled in a manner that material, as well as energy inputs and outputs at its boundary, are elementary Energy inputs/outputs can include production and delivery of fuels, feedstock energy, and process energy used within the modeled system (International Organization for Standards, 2006).

Life Cycle Inventory Analysis

Once the goal and scope are established, the LCI Analysis is completed where the product system (or product systems if there are more than one alternative) is defined by setting the system boundaries, designing the flow diagrams and unit processes, establishing data collection parameters for each process, performing allocation steps for multifunctional processes, and processing data (Guinée, 2002). The flows of all unit processes are related to the reference flow.

A uniform and consistent understanding of the product system is needed to evaluate measured, calculated, or estimated quantitative and qualitative data for each included unit process.

Factors to consider in the LCI Analysis include:

- Drawing process flow diagrams that outline all the unit processes to be modeled, including their interrelationships;
- Describing each unit process in detail concerning factors influencing inputs and outputs;
- Listing process flows and relevant data for operating conditions associated with each unit process;
- Developing a list that specifies the units used;
- Describing the data collection and calculation techniques needed for all data;
- Providing instructions to document any special cases, irregularities, or other items associated with the data provided (International Organization for Standards, 2006).

Data can be classified under the following categories:

- Energy inputs, raw materials, ancillary inputs, other physical inputs;
- Products, co-products, and wastes;
- Releases to air, water, and soil;
- Other environmental considerations (International Organization for Standards, 2006).

Upon completion of this step, a sensitivity analysis is conducted to determine the data to include and to verify the initial analysis. If needed, the initial system boundary is revised, as appropriate, to better define the goal and scope. (International Organization for Standards, 2006).

Life Cycle Impact Assessment

The LCIA phase involves the interpretation of the environmental impacts of the LCI results and is conducted per the goal and scope of the study. LCIA differs from environmental performance evaluation, environmental impact assessment, and risk assessment because it is based on a functional unit. In fact, LCIA can be used to inform these other environmental techniques. The LCIA should evaluate:

- Whether the quality of the LCI data and results are sufficient to conduct the LCIA per the study goal and scope definition;
- Whether the system boundary and data cut-off decisions have been sufficiently reviewed to ensure the availability of LCI results needed to calculate indicator results for the LCIA;
- Whether the environmental relevance of the LCIA results from decreases due to the LCI functional unit calculation, system-wide averaging, aggregation, and allocation (International Organization for Standards, 2006).

The LCIA phase collects indicator results for the different impact categories, and LCIA elements must include:

- Selection of impact categories, category indicators, and characterization models;
- Assignments of LCI results to the selected impact categories;
- Calculation of category indicator results (characterization) (International Organization for Standards, 2006).

Impact categories selection must be justified and consistent with the goal and scope of the LCA and reflect comprehensive environmental issues related to the product system being studied.

Each impact category requires the following components in the LCIA:

- Identification of category endpoint(s),
- Definition of the category indicators for given category endpoint(s),
- Identification of appropriate LCI results that can be assigned to the impact category, accounting for the chosen category indicators and identified category endpoint(s), and
- Identification of the characterization model and the characterization factors (International Organization for Standards, 2006).

Three main classes of impact categories include human health, ecosystems, and resources, yet other potential LCIA categories can be selected based on:

- International agreement or approved by a competent international body;
- Aggregation of input and output impacts of the category endpoints;
- Minimization of the value choices and assumption;
- Avoiding double counting unless required by the goal and scope definition, for example when the study includes both human health and carcinogenicity;
- Being scientifically and technically valid and based upon a distinct, identifiable environmental mechanism and reproducible empirical observation;
- Identifying the extent to which the characterization model and the characterization factors are scientifically and technically valid; and
- Considering the environmentally relevant category indicators (International Organization for Standards, 2006).

The environmental relevance of an impact should clearly reflect the consequences of the LCI results on the category endpoint. Additional environmental data or information to the characterization model per the category endpoints can include:

- The condition of the category endpoints,
- The relative magnitude of the assessed change in the category endpoints,

- The spatial aspects, such as the area and scale.
- The temporal aspects, such as the duration, residence time, persistence, timing, etc.,
- The reversibility of the environmental mechanisms, and
- The uncertainty of the linkage between the category indicators and the category endpoints (International Organization for Standards, 2006).

Life Cycle Interpretation

The Life Cycle Interpretation phase involves the analysis and evaluation of the LCIA results to determine their soundness and robustness to draw an overall conclusion. Interpretation is comprised of the following steps:

- Identification of the significant issues based on the results of the LCI and LCIA phases of LCA;
- Evaluation considering completeness, sensitivity, and consistency checks;
- Consideration of conclusions, limitations, and recommendations (International Organization for Standards, 2006).

The interpretation phases also consider the appropriateness of the definitions of the system functions, the functional unit, and system boundary, as well as limitations identified by the data quality assessment and the sensitivity analysis. LCI results are interpreted with caution since they refer to input and output data and not to environmental impacts. Uncertainty is introduced into the results of an LCI due to the compounded effects of input uncertainties and data variability.

Limitations of Life Cycle Assessment

LCA’s holistic nature is both a major strength and limitation. On the one hand, LCA includes all impacts of a system. On the other hand, there is a need to simplify aspects to allow for calculation of impacts of a product’s life, and it does not have the means to evaluate the systems economic, social, and other characteristics. As such, LCA considers global or national information without addressing localized impacts and is static since time elements are not modeled. Available data sets are frequently obsolete, incomparable, or of unknown quality and may not reflect the region of LCA evaluation. Data are generally available in blocks, for example, combinations of processes, such as electricity production or aluminum production, rather than the individual consulting processes themselves. The process models focus on the physical characteristics of industrial activities and other economic processes but do not include market mechanisms or secondary effects on technological development (Guinée, 2001).

Though the ISO standardization process plays an important role in avoiding arbitrariness, important methodological choices remain free to be made such as choice in time perspective, study assumption, sources of input data, allocation of environmental burdens to different life cycles, and modeling of environmental impacts (Ekvall & Finnveden, 2000). These methodological choices can cause variability in the LCA process. The environmental impacts are often described as "potential impacts" because they are not specified in time and space, are related to an arbitrarily defined functional unit, and involve many technical assumptions and value choices. Yet an important aim is to make these assumptions and choices as transparent as possible (Guinée, 2001).

Screening Life Cycle Assessment

Screening LCAs can be utilized in the early stages of a product or system development to produce an initial overview of product system environmental impacts when limited data is available (Fleischer & Schmidt, 1997). They serve to adapt the LCA methodology and simplify it for use in the early product design stages, such as an architect's draft or a research project, where the goal is to identify research areas that require additional, in-depth assessment (European

Union Environmental Research and Innovation, 2012). Screening LCAs do not provide detailed environmental impact results and is not intended for external publication.

The Screening LCA study focuses on the main contributors to the system, such as the input of materials, water, and energy use, and transportation of elements, ensuring omitted aspects are not significant for the environmental indicators considered. The process can be used to evaluate one single indicator or a limited number of indicators, for example, global warming potential (GWP) and total use of renewable primary energy resources (European Union Environmental Research and Innovation, 2012). Screening LCAs are typically based on generic assumptions, according to the study's goal and scope, and attempt to represent impacts of the region studied. Five major areas representative of data include geography, technology, age, time, and precision. Geographic data related to the country or region where materials are gathered and used to the best of the researchers' ability and understanding. Data should represent the technology used as closely as possible. Average environmental quantitative information on the system or product may be taken from generic LCA data or default values for major components. For consistency, a qualitative assessment is made to determine if the LCA methodology is applied uniformly to the various components and processes per the goal and scope of the study (European Union Environmental Research and Innovation, 2012)

Applications for Screening LCAs include:

- Identifying environmental optimization potentials in the early design stages for buildings (for an architect or stakeholder, helping to improve the building design).
- Developing supporting documentation for an architectural competition.
- Comparing innovative new product and an existing one (e.g., within a company).

Streamlined Life Cycle Assessment

Between the Full LCA and Screening LCA lies the SLCA, also referred to as a Simplified LCA. SLCA is an efficient tool to evaluate the environmental attributes of a product, process, or service's life cycle (T. Graedel & Saxton, 2002). SLCA is not meant to be a rigorous quantitative determination; however, it is a tool for identifying environmental 'hot spots' and highlighting key opportunities for creating environmental improvements. SLCA follows the LCA ISO 14040 steps of goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and interpretation. SLCA is not intended to be a rigorous quantitative determination but is intended to provide an understanding of environmental impacts for evaluation. SLCA is best applied during preliminary evaluation of the environmental impacts of a product system (Lee, Kim, Kwon, & Hur, 2003).

SLCAs provide a complete and rigorous assessment to guide industry and serve to aid environmental assessment while intending to no be difficult or impossible to perform (Thomas E Graedel, 1998). The Streamlined LCA process is achieved by limiting the system boundary, data collection, and analysis. SLCAs can be iterative, and once the system is better understood, additional components can be evaluated for evaluation. (Pommer, Bech, Wenzel, Caspersen, & Olsen, 2003).

Specifically, the goal and scope definition process can be streamlined, and smaller sub-segment of a life cycle or product can be considered. Goal definition entails identifying the intended use(s) of the results, determining the type of analysis needed, and interpreting the results. Scope definition entails identifying what, how much, and what level of detail and quantity of information is collected for the life cycle stages, environmental releases, and impacts on human health and the environment. SLCA requires a clear goal and scope, with a thorough understanding of the evaluated system (Weitz & Sharma, 1998). Streamlining can be achieved by:

- Removing upstream or downstream components,
- Partially removing upstream components,
- Removing both upstream and downstream components,
- Using specific entries to represent impacts,
- Using specific entries to represent LCI,
- Using “showstoppers” or “knockout criteria,”
- Using qualitative or less accurate data,
- Using surrogate process data,
- Limiting raw materials (United States Environmental Protection Agency, 1997b).

The key challenge in SLCA development is ensuring the streamlining choices are consistent with the goal of the study and that the subsequent results will be adequate to support that goal. SLCA should not be a truncated Full LCA. Instead, the SLCA should determine what is needed to be included within the SLCA. The process needs to include consideration of the factors that may be significantly affected by streamlining. There is no one-size-fits-all set of streamlining options, though practitioners have developed guidance to aid in the streamlining process (Weitz & Sharma, 1998).

Steps to ensure the SLCA is not oversimplifying a problem include:

- *Screening the product with an inviolate list:* Some activities or choices are simply incorrect from an environmental standpoint and do not need to be evaluated. An example is the use of mercury switches in a product or the use of CFCs in manufacturing since these elements have most likely been replaced by other more environmentally friendly items.

- *Limiting or eliminating components or processes deemed to be of minor importance:* Omit certain aspects of a system that may not have a major impact on the system and for which information may be difficult to obtain.
- *Limiting or eliminating LCA stages:* The LCA stages can be limited to facility operations, known as gate-to-gate, rather than cradle-to-grave. This approach does not evaluate every component in a product's life but will provide a reasonable amount of information for evaluation. Another technique is to limit or eliminate upstream processes, such as resource extraction outside of the gate of the product system that may not be relevant to evaluate. Additionally, the concept of cradle-to-warehouse can be used, since a manufacturer has no control over the use of their product once it leaves the warehouse.
- *Including only selected environmental impacts:* Impacts can be limited to those perceived to have the highest importance, or that can be readily quantified. This process can be responsive to public pressure rather than environmental science and tends to be anthropocentric rather than balanced.
- *Including only selected inventory parameters:* If select impacts of interest are evaluated, only the inventory data needed to evaluate those impacts will be gathered.
- *Limiting consideration to constituents above threshold weight or volume values:* Consider only major constituents or modules of the system, which overlooks small but potent constituents (for example, it would fail as a tool for an SLCA of medical radioisotope equipment) and may require more justification and only applies to quantitative assessments.
- *Limit or eliminate impact analysis:* LCI cannot be removed from LCA since it will fail to meet the requirement of the ISO standard. But, the LCI process can be abridged, which results in an overall assessment of "less is better" philosophy. While pursuing such an approach will probably result in useful actions, the approach does not connect between the knowledge base of environmental sciences and the recommendations made by the abridged LCA.
- *Using qualitative rather than quantitative information:* Quantitative data are often difficult to acquire or may not even exist. Conversely, qualitative data can be sufficient to reveal the potential for environmental impacts at different life stages.

However, the qualitative approach makes it difficult to compare one product to another or with a new design if the ratings are quite similar.

- *Using surrogate data:* Utilizing surrogate data on similar material, module, or process maybe be helpful when the specific data desired for an assessment are not available. The use of surrogate data is often contentious and has many of the same limits in usefulness as qualitative data (Thomas E Graedel, 1998).

Based on the review of these particulars, it is recommended that a valid SLCA evaluates all relevant life cycle stages in some manner as well as develop and evaluate all relevant environmental stressors (Thomas E Graedel, 1998).

Streamlined Life Cycle Assessment Assets and Liabilities

As an SLCA is developed, there are concerns that significant elements of the Full LCA are lost. For many projects, Full LCAs will never be completed for an evaluation; therefore, the SLCA provides an adequate evaluation of environmental impacts. SLCAs have more limitations than LCAs in the following ways:

- SLCAs have little to no capacity to track overall materials flows. For example, during the SLCA process, a particular material may be tracked within a corporation, yet there might be limited information on whether its use in a particular product is a significant fraction of total corporate usage.
- SLCAs have the minimal capability to compare completely dissimilar approaches to filling a need.
- SLCAs have the minimal capability to track improvements over time (Thomas E Graedel, 1998).

Yet, there are several ways that SLCA is useful in the LCA process:

- SLCAs are much more efficient, only taking several days or weeks to complete instead of several months.
- SLCAs are less costly since they can be done by existing staff and within existing job requirements.
- SLCAs are usable in the early stages of design when opportunities for change are great, but quantitative information is limited.
- SLCAs are much more likely to be carried out routinely because of their ease to implement, which allows for easy application to a wide variety of products and industrial activities (Thomas E Graedel, 1998).

Streamlined Life Cycle Assessment Methodologies

Several SLCA methodologies have been established for use in the evaluation of product and system impacts. Two methods discussed in this research are the Materials, Energy, Chemical, and Other Impacts (MECO) Principle and the Environmentally Responsible Product Assessment (ERPA).

Materials, Energy, Chemical, and Other Impacts Principle

The Danish Institute for Produce Development and dk-TEKNIK developed the MECO Principle for use by small to medium-sized companies. The MECO Principle structures the SLCA to systematize and simplify the results. MECO divides the assessment into four environmental impact areas: materials, energy, chemicals, and other impacts. Though materials, energy, and chemicals are understood components of environmental impacts, other impacts are vague since it is meant to cover the "odds and ends" related to the specific study. This process is best suited for quantifiable industrial processes (Volínová, 2011).

The MECO chart (Table 1) is utilized for the evaluation processes, providing an overview of the relevant product life cycle, while performing the inventory and impact assessment at the same time. The advantage of the MECO structure is that the individual sources of environmental impacts do not overlap in the evaluation of all significant environmental issues. It is important to consider during the use of the MECO Chart whether the chart provides a sufficient basis for making the desired evaluation or if additional evaluations need to be completed.

Table 1: MECO Assessment Parameters

	Raw Materials	Production	Use	Disposal	Transport
Materials					
Energy					
Chemicals					
Other					

Source: (Wenzel, H., Hauschild, M., Alting, 1997)

MECO evaluates the inflows and outflows one category at a time based on the established functional unit and chosen life cycle phase. "Materials" category includes all the materials needed to produce, use, and maintain the product. "Energy" category includes all the energy used during a product's life cycle and can include the energy used in the supplying of the materials "Chemical" category includes all the chemicals used in the product's life cycle. Chemicals are classified as type one, two, or three, with one being a problematic substance, and two and three being less problematic. "Other" category is intended to evaluate environmental impacts that do not fall into the other three categories (Hochschorner & Finnveden, 2003). When combined, the four categories represent all terminal environmental exchanges, each with their type of resource consumption and impact potentials and representing typical areas of improvement in product development. MECO streamlines LCA by allowing for easier understanding and relating to the product being evaluated, especially when used in product development decision-making (Wenzel, H., Hauschild, M., Alting, L., 1997).

Environmentally Responsible Product Assessment

The ERPA process identifies critical aspects of a product's life cycle phases, through a fast, qualitative, or semi-qualitative evaluation of environmental impacts at each life cycle stage (Marco, Endris, Ezgi, & Gokan, 2014). ERPA relies on the use of a semi-quantitative matrix method, where a 5x5 matrix evaluates five life cycle stages for five environmental impacts (Hochschorner & Finnveden, 2003). A generic ERPA matrix is shown in Table 2. Each matrix element, or cell, is given an environmental performance score between 0 and 4, where 4 represents superior environmental performance, and 0 represents the worst scenario. A rubric for scoring is provided to aid in the evaluation of each environmental factor and (T. E. Graedel, Allen, & Comrie, 1995; Hur, Lee, Ryu, & Kwon, 2005). A product's total environmental impact is calculated as a sum of the matrix element values. This implies that all cells are given the same weighting, irrespective of the importance of each life cycle stage or environmental impact.

Table 2: ERPA Matrix

	Environmental Impact				
Life Cycle Stages	Waste Managed	Energy	Air Emissions	Water Emissions	Land Emissions
Stage 1					
Stage 2					
Stage 3					
Stage 4					
Stage 5					

Application for Streamlined Life Cycle Assessment

Lee et al. (2003) evaluated the use of ERPA for the environmental impact of cellular phone and vacuum cleaner systems. Since Full LCAs are difficult to apply at the design stage of a project due to their tedious, expensive, and time-consuming attributes, the authors wished to evaluate streamlined methods that involve less cost, time, and effort, yet still provide results similar to a Full LCA. Additionally, the study developed and used a matrix method that provided quantitative information. The study found that these methods are useful in evaluating improvements. But the authors determined that the environmental performance scores of ERPA were subjective, and finding data to support score estimation was difficult (Lee et al., 2003).

Hochschorner and Finnveden compared MECO and ERPA methods to evaluate electric cars and cars with combustion fuel. The MECO method outputs provide both quantitative and qualitative data in its evaluation. The use of the “other” category allows for the addition of relevant information not included in the materials, energy, or chemical categories. Less information is provided on the traditional impact categories, yet more consideration is made fir toxic substances as compared to Full LCAs. ERPA gives semi-quantitative information on environmental stressors, which, in contrast to the MECO method, can be aggregated to a single value if all matrix elements are given the same weighting (or if the modified weighting of the elements has been carried out). SLCAs use depends on the availability of the required information and the user's experience. The MECO method is best suited for studies where materials and chemicals components of the product, while ERPA focuses on the environmental performance during a product's life. The selection of an SLCA method involves a balance between simplification of the method, type of results the user intends to find, based on the goal and scope of the study and the study-specific parameters (Hochschorner & Finnveden, 2003).

To implement these SLCA methodologies, there is a reliance on individuals with some expertise in the evaluated product or system. Expert input is required for accurate tool completion and interpretation and, therefore, can add extra cost or constraint to product development (Birch, Hon, & Short, 2012). Though SLCAs provide fairly comprehensive assessments during the early phase of product development, they lack flexibility and are subject to arbitrariness (Hochschorner & Finnveden, 2003). They represent the perspectives and environmental understanding during the era in which they were developed. Often these methods focus on the most visibly apparent aspects of pollution, such as landfilling and packaging, rather than global warming and biodiversity (Guinée et al., 2011). ERPA is limited in its ability to evaluate indirect impacts, such as the difference between electricity sources or material production technologies. Additionally, qualitative information cannot be directly inputted in the ERPA matrix, which forces the absence of potentially useful information in an evaluation (Hung, Ager-Wick Ellingsen, & Majeau-Bettez, 2018). Yet ERPA is simple to implement when limited technical information is available.

Decision-Making

"Decision-making" refers to making structured choices among alternative courses of action, including one of which may be no action or inaction. There are different levels of organizational decisions, such as strategic decisions, tactical decisions, and operational decisions, which are intended to aid in more efficient operations. Types of decision models applicable to organizations discussed further are:

- Rational Decision-Making Model,
- Boundary Rationality Model,
- Intuitive Decision-Making Model (Open Textbook Library, n.d.).

Rational Decision-Making Model

The rational decision-making model describes a series of steps the decision-maker should when maximizing the quality of the outcomes. The model involves participation in the following steps:

1. *Identifying and defining the problem*: This involved identifying and describing the problem by defining the current and desired states and the alternatives. It is important to identify the cause of the problem and not the symptoms. The gap between the current state and the desired state must be defined to motivate the stakeholders to implement the decision. All available options must be defined and not just the quickest solutions.
2. *Identify the decision criteria*: This step outlines all the criteria ahead of time, which serves as a guide to the decision-making process.
3. *Weight established criteria*: This step allows the criteria to be weighed since it is unlikely each criterion has the same level of importance. It must be accomplished in ways where absolute comparison or relative comparison can occur. Absolute comparison involves side by side comparison of criteria, and criteria are evaluated independently on their specific metrics. Relative comparison is made by comparing each criterion with another, allowing for the determination of which criteria are most important to the decision-maker.
4. *Generate a list of alternatives*: Once the criteria are identified and weighted, as many alternatives as possible are generated, with the intention to find an effective solution.
5. *Evaluate the alternatives*: This step includes the evaluation of the alternatives identified using the previously identified criteria, with the level of effort based on the number of criteria and alternatives being evaluated.
6. *Determining the optimal decision*: This step determines the optimal decision by mathematically ranking or weighting the alternatives. Since criteria have a different level of importance, the calculated rankings are used to assign more influence to the results in the categories that have more importance (Open Textbook Library, n.d.).

The decision is implemented after the selection process is complete. Considering all potential alternatives and criteria can make the ability to develop a final decision difficult. Limiting the number of alternatives is sometimes necessary, but challenging since it can cause a failure in the decision-making process (Nutt, 1994). Guidance for the decision-making process is necessary to clearly define the purpose of the process, set the objectives, conduct a comprehensive alternative search, identify appropriate stakeholders, and avoid the use of opinions in the execution of the decision-making process (Nutt, 1998).

Two concepts should be considered in the use of the rational decision-making process. First, it is important to establish the criteria before searching for alternatives. This prevents the developer from being biased towards one alterative and developing criterion, which can cause alternatives to be chosen preferentially and all potential alternatives to be selected. This will allow for the most effective decision to be made (Open Textbook Library, n.d.).

Second, since the rational decision-making model involves some unrealistic assumptions, stakeholders need to understand the decision being made, understand the available alternatives, have no perceptual biases, and want to make the optimal decision. Also, analysis paralysis can occur when more time is spent gathering information and thinking about it rather than making a decision. The decision process may be used to make a short term or interim decision rather than a final decision (Open Textbook Library, n.d.).

Bounded Decision-Making Model

The Bounded Rationality Model recognizes the limitations of the decision-making process and asserts that individuals knowingly limit their options to a manageable set. The perceived best alternatives are selected without conducting an exhaustive search for all potential alternatives.

The decision made with this model will be good enough and not absolute in the outcome. Decision-makers accept the first alternative that meets the minimum criteria. Though similar to rational decision-making, it is saving time and effort by excepting the first alternative that meets the minimum standards, rather than choosing the ultimate best choice (Open Textbook Library, n.d.).

Intuitive Decision-Making Model

The intuitive decision-making model involves arriving at a decision without any conscious reasoning. Decision made often made under challenging circumstances with time pressure, constraints, uncertainty, and highly visible and high-stakes outcomes and within changing conditions. In these cases, there is limited time to develop formal decision-making model processes. To an outside observer, it may appear as guessing, when in fact, the decision-makers use intuition from experience to make decisions. Intuitive decision-makers scan the environment for cues to recognize patterns, and once established, they aid in developing a course of action. In this model, only one choice is considered at a time. Novice decision-makers may not have prior experiences to aid them in intuitive decision-making (Open Textbook Library, n.d.).

Multicriteria Decision Analysis Methodologies

Multicriteria Decision Analysis Methodology (MCDA) is a rational-decision-making model that utilizes decision-making theory and methodology to aid in the evaluation of complex problems. It provides structure to the decision-making process to gain consensus between attributes and objectives (Achillas, Moussiopoulos, Karagiannidis, Banias, & Perkoulidis, 2013). MCDA refers to a group of methods for improving understanding of complicated decision-making processes by (1) structuring the problem through the identification of criteria, (2) eliciting the parameters of the model (alternative, criteria, preference thresholds), and (3) applying decision algorithms to rank alternatives from most preferred to least preferred (Linkov & Seager, 2011).

Various methodologies to support decision-makers in their unique and personal decision-making process are contained in MCDA. One process is that MCDA provides structured techniques for finding a compromised solution. This process is not automated or computer-driven, allowing all decision-makers to participate in the same decision-making process. Subjective information is incorporated by the decision-maker in the MCDA process, leading to a compromise in the solution. MCDA integrates mathematics, management, informatics, psychology, social science, and economics into the decision-making process. A variety of software such as spreadsheets with embedded computations, ad hoc implementations, off-the-shelf, web and smartphone applications, are implanted in the MCDA, allowing it to be an accessible decision-making tool (Ishizaka & Nemery, 2013). The goals of these methodologies are to allow for stakeholders to be able to access the decision making process in a variety of setting such as in a personal setting or withing a group setting.

Four basic types of problem formulation types have been identified for MCDA:

1. *Choice Problem*: aims to help determine the “best” action or elaborate a selection procedure. The goal is to select a single best option or reduce the group of options to a subset of equivalent or incomparable ‘good’ options.
2. *Sorting Problem*: helps to sort actions according to their intrinsic value or to formulate a segmentation procedure into ordered and predefined groups or categories. The options

are regrouped based on similar behaviors or characteristics for descriptive, organizational, or predictive reasons. The resulting classifications potentially lead to measures to make systematic changes. It is often used as an initial screening to reduce the number of options to be considered in the subsequent step.

3. *Ordering problem*: helps to order the actions according to a decreasing preference order or to elaborate a ranking procedure. Options are ordered from best to worst by means of scores or pairwise comparisons. The order can be partial if incomparable options are considered, or complete.
4. *Description Problem*: helps to describe the actions and/or their consequences in a systematic way and to elaborate on a cognitive procedure. The goal is to describe options and their consequences and is typically done in the first step to understanding the characteristics of the decision problem (Roy, 1981).

Additional problem formulations under MCDA have been identified and include:

1. *Elimination Problem*: Allows for the elimination of elements as a branch of the sorting problem (Bana E Costa, 1996).
2. *Design Problem*: Allows for the identification or creation of new actions to meet the goals and aspirations of the decision problems (Keeney, 1992).
3. *Elicitation Problem*: Aims to elicit the preference parameters (or subjective information) for a specific MCDA method from several decision-makers during group decision making (Ishizaka & Nemery, 2013).

The following MCDA methodologies have been applied to solve elimination, design, and elicitations problems are listed below and categorized in Table 3:

- Analytical Hierarchy Process (AHP)

- Analytical Network Process (ANP)
- Multi-Attribute Utility Theory (MAUT)
- Preference Ranking Organization Method for Enrichment and Evaluations (PROMETHEE)
- Elimination - Et Choix Traduisant la REalite (ELECTRE)
- Technique for Order of Preference by Similarity to Ideal Solutions (TOPSIS)

Table 3: MCDA Problem Types and Methods

Choice Problems	Ranking Problems	Sorting Problems
AHP	AHP	AHPSort
ANP	ANP	
MAUT	MAUT	
PROMETHEE	PROMETHEE	
ELECTRE I	ELECTRE III	ELECTRE-Tri
TOPSIS	TOPSIS	

Source: Ishizaka & Nemery, 2013

Three different approaches to solving MCAD problems include the full aggregation approach, the outranking approach, and the goal, aspiration, or reference level approach. The full aggregation approach involves evaluating a score for each criterion, which is synthesized into a global score. This approach assumes compensable scores, meaning a bad score for one criterion is compensated for by a good score over another. AHP, ANP, and MAUT are used to evaluate decisions using this approach. The outranking approach involves the understanding that a bad score may not be compensated for by a better score. The options order may be partly due to the notion that incomparability is allowed. Two options can have the same score, but their behavior may be different and, therefore, incomparable. Outranking approaches include PROMETHEE and ELECTRE. The goal, aspiration, or reference level approach involves defining a goal for each criterion and then identifying the closest option to the ideal goal or reference level. TOPSIS can be used in this type of evaluation (Ishizaka & Nemery, 2013). Further discussion of these methodologies is presented below.

Aggregation Approaches

Analytical Hierarchy Process

Thomas Saaty developed AHP to resolve decision-making problems by breaking them down into sub-problems, then aggregating results to obtain a final recommendation. The method allows stakeholders to organize and express their judgments or feeling the overall components of the decision-making process. These components, which include a goal, evaluation criteria, and alternatives, are compared through pairwise comparison as a straightforward and structured way to understand and evaluate the problem (T Saaty, 1980).

AHP guides the developer to breakdown the decision problem into three main phases to generate the priorities over the set of alternatives:

1. Structure of the decision problem as a hierarchical structure.
2. Construct a set of pairwise comparison matrices.
3. Calculate the priorities of the elements in the hierarchical structure.

The AHP structure involved developing the evaluated problem into three tiers. The top tier is the goal of the decision problem, the second tier is a set of criteria, and the third tier is the set of alternatives. The second and third tiers can be expanded by adding sub-criteria to the second tier to allow for further evaluation. Figure 2 presents the basic three-tier hierarchy.

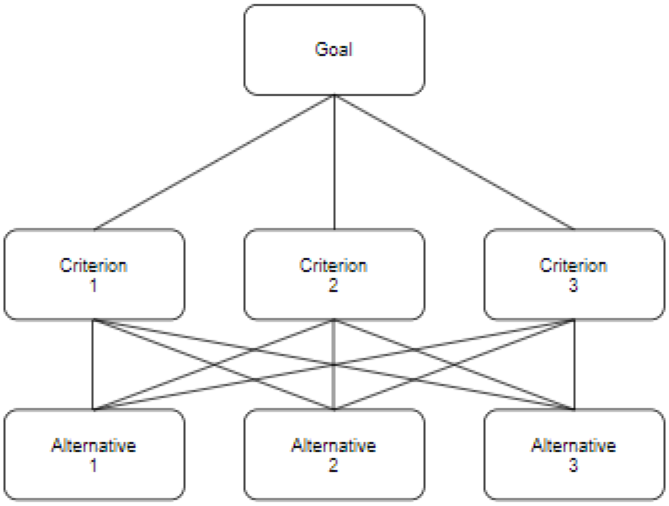

Figure 2: Analytical Hierarchy Process Diagram

The second step of AHP involves the pairwise comparison of each tier with respect to the tier above. For example, the second-tier criteria are compared in a pairwise manner with the goal of the decision problem. The purpose is to compare the relative importance of each criterion with respect to the other criterion on an importance assessment scale of 1 to 9, which is shown in Table 4 with the verbal description of each importance level. Next, each alternative is compared in a pairwise manner with respect to each criterion (the tier above) (Palomares Carrascosa, 2018).

Table 4: Saaty AHP Importance Scale

Importance Level	Verbal Assessment
9	Extreme Importance
8	Very, very strong
7	Very strong or demonstrated importance
6	Strong plus
5	Strong importance
4	Moderate plus
3	Moderate importance
2	Weak or slight
1	Equal importance (indifference)

Source (T Saaty, 1980)

The third phase of the AHP calculates priorities or scores of the elements in each comparison matrix to provide a prioritization value, of the importance of each decision-making problem. Priorities are calculated using a matrix with the eigenvalue, or similar linear algebra method is used. The results are used as weights to calculate an overall priority at each tier (Palomares Carrascosa, 2018). Sensitivity analysis can be conducted to determine how changes in ranking may affect the outcomes of the evaluation process. For example, changing the weighing of a single criterion weight or the performance value of data of a given problem may cause a difference in the prioritization of alternatives selected. The decision-maker can make better decisions if they can determine how critical each criterion is by evaluating how sensitive the actual ranking of the alternatives is to change in the weights provided in the evaluation (Triantaphyllou & Sanchez, 1997).

Analytical Network Process

The Analytical Network Process Method (ANP) is a modification of AHP which considers dependencies between criteria. In AHP, there is an assumption that the criteria are independent, but if they are not independent, correlated criteria will result in an over-valuated weight in the decision. Dependencies may imply a heavier weight of joint criteria, which can be calculated using ANP. ANP is closer to reality since criteria are often dependent on each other in some way and this process yields more accurate results. Clusters, containing nodes or elements are used instead of tiers.

Multi-Attribute Utility Theory

Multi-Attribute Utility Theory (MAUT) is based on the main hypothesis that every decision-maker tries to optimize, implicitly, or consciously, a function which aggregates all points of view. The decision maker's preferences are represented by the utility function, which is not necessarily known at the outset of the decision process (Ishizaka & Nemery, 2013). The utility function measures the desirability or the preference of alternatives. The utility score is calculated to evaluate the degree of well-being those alternatives provide to the decision-maker. The utility function is made up of various criteria allowing for the assessment of the global utility of an alternative. For example, for consumer goods, the utility is usually based on criteria such as price, size, and consumer reviews. The decision-maker gives a criterion a score, known as the marginal utility score, which is aggregated into the global utility score that allows the ranking of the alternatives from best to worse (Ishizaka & Nemery, 2013). No issue of incomparability between two alternatives exists since two utility scores are always comparable. (Ishizaka & Nemery, 2013).

Outranking Approaches

Preference Ranking Organization METHod for Enriched Evaluation

Preference Ranking Organization METHod for Enrichment Evaluation (PROMETHEE) allows the decision-maker to rank actions based on preference degrees. The three main steps of PROMETHEE are:

1. The computation of preference degree for every ordered pair of actions on each criterion.
2. The computation of unicriterion flows.
3. The computation of global flows.
4. The results, based on the global flows, provide a ranking of actions as well as a graphical representation of the decision problem (Ishizaka & Nemery, 2013).

PROMETHEE calculates a preference degree of how an action is preferred over another action as a score between 0 and 1. A score of 1 represents a total or strong preference for the actions of the criterion considered, and 0 means there is no preference at all. If the decision-maker falls between these values, some preference exists. PROMETHEE allows the decision-maker to evaluate the unicriterion preference degrees in a pairwise manner. An important element of PROMETHEE is how the decision-maker perceives the difference between the objective evaluations measured on every specific criterion (Ishizaka & Nemery, 2013). Conclusions are difficult to interpret, especially when the number of actions is large. Therefore, criterion pairwise preference degrees are summarized in a) unicriterion leaving, or positive flows, b) entering, or negative flows, and c) net flows to measure how an action is preferred over all other actions.

Several versions of PROMETHEE have been developed to evaluate preference degrees. PROMETHEE I ranking is based on the positive and negative flows. In this ranking method, four different scenarios are used when analyzing the flows of two actions:

1. One action is a better rank than another if its global and negative flows are simultaneously better.
2. One action has a worse rank than another if both global positive and negative scores are worse.
3. Two actions are said to be incomparable if one action has a better global positive score but worse global negative score (or visa-versa).
4. Two actions are called indifferent if they have identical positive and negative flows.

PROMETHEE II ranking is based on the net flows only and leads to a complete ranking of actions. Therefore, there are no incomparable occurrences. The actions can be ordered from the best to the worse (Ishizaka & Nemery, 2013).

Preference Elimination Et Choix Traduisant la REalite

Elimination Et Choix Traduisant la REalite (ELECTRE) which utilizes pairwise comparison to compare to all other options using the Electre III-IV software. Pairwise comparisons allow for final recommendations can be drawn (Ishizaka & Nemery, 2013). The main characteristic and advantage of the ELECTRE is that they avoid compensation between criteria and any normalization process, which can distort the original data. ELECTRE I was developed by B. Roy in 1965. ELECTRE improvements allow for tackling of new decision problems; ELECTRE I, Iv, and Is were developed to evaluate choice problems, ELECTRE II, III, and IV were developed to evaluate ranking problems, and ELECTRE Tri-B and Tri-C were developed to evaluate sorting problems (Ishizaka & Nemery, 2013).

ELECTRE methods are relevant when facing decision problems with two or more criteria with at least one of the following conditions is satisfied:

- The performances of the criteria are expressed in different units, and the decision-maker wants to avoid defining a common scale, which is difficult and complex.
- The problem does not tolerate a compensation effect.
- There is a need to use indifference and preference thresholds, such that small differences may be insignificant, although the sum of the small differences is decisive.
- The options are evaluated on a scale presenting an order or on a ‘weak’ interval scale, where it is difficult to compare differences.

ELECTRE I, IV, and IS, solve choice problems, allowing decision-makers to select the smallest subset containing the best options amongst a given set of options. The difference between ELECTRE I and IV is the introduction of the veto concept, which is utilized if an option performs badly on a single criterion compared to another option, the option will be considered outranked, or irrespective of its performance on another criterion. ELECTRE IS utilizes pseudo-criteria to model the fact that a decision-maker might not have a preference between two options of a criterion based on their performance difference. It is also used to reflect a situation where the preferences might be strong if the difference is higher than a preference threshold. The thresholds allow situations to be handled where data are imprecise or uncertain (Ishizaka & Nemery, 2013).

ELECTRE II, ELECTRE III, and ELECTRE IV utilize ranking methods, which may lead to a partial order on a set of options, without assigning a score to the alternatives. The method’s output is the preference order, without scores. ELECTRE II and ELECTRE III uses pseudo-criteria and outranking degrees, instead of binary outrank relations. ELECTRE IV does not require the weighting of criteria and is the most used ranking method (Ishizaka & Nemery, 2013).

ELECTRE Tr- B (commonly known as ELECTRE-Tri) and ELECTRE Tri-C are sorting methods that enable the independent assignment of a set of options to one or several predefined categories. These methods allow for the classification of categories by preference from best to worse. A drawback to the ELECTRE method is that they require various technical parameters, which means they may be difficult to be fully understood by users. As a result, research is underway to develop automatic elicitation of those parameters, where decision-maker rank options that have a clear ranking order to infer parameters such as weights or the criteria, and the thresholds. Yet, this method may show that the decision-maker has inconsistencies or contradictions, which means re-evaluating the judgments (Ishizaka & Nemery, 2013).

Goal, Aspiration or Reference Level Approach

Technique for Order of Preference by Similarity to Ideal Solutions

Technique for Order of Preference by Similarity to Ideal Solutions (TOPSIS) is a widely used method to solve multicriteria ranking problems such as supply chain management and logistics, design engineering and manufacturing systems, and energy management decisions. TOPSIS utilizes compromise programming, which aims to set an ideal solution as a reference point according to experts' preferences and then seek those solutions whose attributes are closest to the ideal solution's attributes. In application, TOPSIS defines two fictitious alternatives known as positive and negative ideal solutions. The positive solution represents the best alternatives assessment on each criterion, while the negative ideal solution reflects the worst ones. The geometric (Euclidian) distance between each decision alternative is calculated for positive and negative ideal solutions. The alternative closest to the positive ideal solution and farthest from the ideal negative point is considered the best alternative among those evaluated (Palomares Carrascosa, 2018).

TOPSIS requires only a minimal number of inputs from the decision-maker and provides easy to understand results. The only subjective parameters are the weights associated with the criteria. TOPSIS is based on three computational steps:

1. The performances of the different criteria are normalized for comparing the measure on different units. Normalization method types applied include distributive normalization and ideal normalization.
2. The weights determined are considered. A weighted normalized decision matrix is constructed by multiplying the normalized scores by their corresponding weights.
3. The weighted scores are used to compare each action to the positive and negative virtual action.

Three ways developed to define these virtual actions are:

1. Collecting the best and worst performances on each criterion of the normalized decision matrix.
2. Assuming absolute positive and negative points that are defined without considering the actions of the decision problem.
3. Having the decision-maker define the positive and negative points, which must be between the positive and negative points calculated with the two methods explained above? This method is rarely used as it is difficult to elicit.

4. The distances for each action are calculated as compared with the positive and negative points, using the geometric distance.
5. The relative closeness coefficient is calculated for each action, with a value between 0 and 1. An action with a value closest to the positive point will have a value nearest 1, whereas if action is closer to the negative point, it will have a value closest to 0 (Ishizaka & Nemery, 2013).

Decision-Making for Environmental Applications

Decision-making for environmental projects is complex, and it is often difficult to develop consensus on alternatives because of inherent trade-offs between multiple factors. Effective environment decision-making requires explicit structure to coordinate environmental, ecological, technological, economic, and sociopolitical factors relevant to elevating and electing among management alternatives. Each factor has multiple subcriteria, which makes the process multi-objective. Integrating the criteria with respect to human values and technical applications demands a systematic and understandable framework to organize stakeholders and find a defensible decision. Often in environmental decision-making, some alternatives are unfavorable to stakeholders and may be eliminated early due to stakeholder input and the desire to appease stakeholders. Yet, these alternatives may be relevant and important to consider. Therefore, the MCDA structure and methods allow for improved decision-making when risk, multiple criteria, and conflicting interests are involved. The MCDA process allows for technical personnel along with diverse decision-makers and potentially non-technical stakeholders to systematically evaluate alternatives and apply value judgments to derive the most favorable management alternative. Stakeholder involvement is increasingly recognized as essential to successful environmental decision-making. Utilizing MCDA tools can allow for structure inputs to be organized during the evaluation process, along with the results of scientific and engineering studies and cost analysis (Kiker et al., 2005).

Integration of Life Cycle Assessment and Analytical Hierarchy Process Methodologies

There is a need to guide the decision-making process to create clarity about the purpose of the decision process, set realistic objectives for evaluation, conduct a comprehensive search for alternatives, find the appropriate stakeholders to participate, and avoid using their opinions in the execution of the decision-making process (Nutt, 1998). LCA can be paired with MCDA to create an integrated methodology. MCDA can be used in the goal and scope phase of the LCA and be integrated into the data interpretation phase of LCA to allow for evaluation of the environmental impacts along with the addition of other attributes necessary for side by side system evaluation. AHP is appropriate for this application since it allows for the development of preferences to aid in the determination of the best or most preferred alternative.

Research has been conducted to consider the integration of LCA and MCDA. Some researchers feel that there is an urgent need to create an integrated methodological framework for sustainability assessment due to increasingly complex environmental system problems. These problems impact human well-being and ecosystems, which represent a threat to the economic performance of countries and corporations. They propose a computational methodology to integrate life cycle thinking methods, stakeholder analysis supported by MCDA, and dynamic system modeling (Halog & Manik, 2011). The 2011 International Congress on Sustainability Science and Engineering in Arizona argued that to make the notion of sustainable development useful and operational to stakeholders, four aspects have to converge, which include: 1) science and technology must support it, 2) the right policies and regulatory frameworks should be well-formulated, 3) businesses should be actively involved; and 4) public stakeholders must understand and support it by either incorporating their voices in the process and showing the results in understanding interactive manner (Halog & Manik, 2011).

Zanghelini et al. reviewed studies involving MCDA integration with LCA methodology to assess how MCDA techniques are applied to the LCA process to support results interpretation. The most observed use for MCDA was in the LCIA phase of the LCA, where the main goal is to assess the trade-offs between impact categories or between environmental and other criteria such as economic, social, or technical aspects. Weighting Sum Approach (WSA) and AHP are the most observed MCDA methodologies applied. Yet the use of outranking methods was observed due mainly to the non-compensatory or partially compensatory behavior. MCDA is rarely seen for use in the goal and scope phase of the LCA process. Instead, MCDA was utilized in the LCI step, where energy and water demand, along with waste generation, were the main criteria of interest for the decision-making process. LCA does not provide a way to determine the preferable methodological path to solve the final decision issue, especially when there are different stakeholders involved. Therefore, MCDA is useful to aid in final decision or ranking. MCDA aids in completing the evaluation, and Life Cycle Costing (LCC) and Social LCA may also be useful for these evaluations (Zanghelini et al., 2018).

Cinelli et al. evaluated MCDA methods (MAUT, AHP, PROMETHEE, ELECTRE, and DRSA) with respect to 10 criteria for scientific soundness, feasibility, and utility for use in sustainability assessment tools. MAUT and AHP are simply understood by users and stakeholders. MAUT, ELECTRE, PROMETHEE, and DRSA were useful in handling uncertain information utilizing probability distributions and thresholds. AHP, PROMETHEE, ELECTRE, and DRSA were observed to have the potential to suffer from rank reversal. PROMETHEE and

AHP have more software choices than other MCDA methods. Based on existing use, the authors ranked the methods from easiest to most difficult to use as DRSA, AHP, PROMETHEE, MAUT, and ELECTRE. Yet the authors feel there is no one perfect methodology for the sustainability assessment, and they should be evaluated on a case by case basis for use (Cinelli, Coles, & Kirwan, 2014).

As an example, LCA was used in conjunction with AHP to provide a sustainability assessment for waste management systems (WMS) in Nis, Serbia. LCA assessed the environmental impact of developed scenarios and to calculate the values of the impact categories (indicators). Next, AHP was used to rank developed scenarios according to the goal: the selection of the scenario with minimum negative environmental impact according to the indicators. The environmental impacts were evaluated for four waste management scenarios: 1) current operations, 2) recycling and landfilling, 3) incinerating, and 4) recycling and anaerobic digestion. The LCA was completed using the LCA-IWM Assessment Tool developed by de Boer as a decision support tool for waste management planning (Den Boer, Den Boer, & Jager, 2007). The LCA output was presented to experts involved with the research. The LCA results, the experts' experience, and subjective opinions were used in the AHP pairwise comparison process. The methodology was successful in allowing stakeholders to rank the alternatives based on the LCA output (Milutinovic, Stefanovic, Đeki, Mijailovic, & Tomic, 2017).

For evaluating food waste in Rio de Janeiro, LCA, and MCDA integrated to assess potential system operation scenarios. EASETECH software, developed by the Technical University of Denmark, to perform LCAs of complex systems handling heterogeneous materials flows, was used to determine the impact of four scenarios. The LCA results were inadequate for identifying trade-offs between scenarios. To overcome this, MCDA was utilized to allow for evaluation of the LCA results for decision analysis. MAUT, ELECTRE, PROMETHEE, and Stochastic Multi-Attribute Analysis (SMAA) were evaluated for use with LCA, but Variable Interdependent Parameters – Analysis (VIP-Analysis) software was selected for use. Developed by Dias and Climaco, the software does not require precise values for scaling/constants/weights. Instead, it accepts imprecise information on these values, usually identified in an indirect way, by ordering scaling constants, etc. The analysis includes assigning values of one, two, and three for each evaluating criterion, with 1 indicating the lowest impact. The study found that the integration of LCA and the VIP-Analysis software aided in the selection of the most preferable environmental option to treat waste but was also useful in assessing different and conflicting criteria such as social and economic aspects. This methodology was useful in prioritizing the evaluated scenarios (Angelo, Saraiva, Clímaco, Infante, & Valle, 2017).

For selecting sustainable waste to energy technologies for municipal solid waste (MSW) treatment, a framework was developed to compare life cycle sustainability impacts of options using game theory. A weighting scheme was developed, combining impacts based on stakeholder preferences. Game theory was applied to help stakeholders fairly share the costs and benefits and was used as a guide to reach an agreement on a mutually sustainable and reasonable solution. The Full LCA was completed using SimaPro LCA system software developed by Pre Sustainability. Since the LCA does not evaluate economic and social impacts, LCC was used to determining the economic aspects of the scenarios. The social sub-criteria evaluated included:

- Proximity to residential areas (e.g., noise, odor)
- Workers and neighborhood safety
- Employment
- Affordability
- Public acceptance
- Land use

MCDA methods were evaluated, but it was noted for MCDA that stakeholders should first agree on criteria of interest and the importance of each criterion. If stakeholders have conflicting priorities over criteria, reaching an agreement can be difficult. MCDA does not consider stakeholders' conflicts and their influences on each other in reaching a mutual decision. Instead, game theory allows for analyzing trade-offs between environment and economy aspects and considered stakeholders' conflicts and dialogues. Game theory was used to complement AHP, LCA, and LCC to model the dialogues among stakeholders and guide them to reach a sustainable solution. The study utilized two hypothetical and diverse stakeholders with conflicting priorities. The study found that agreement could be made, yet there were challenges in providing accurate data and real scenarios that represented the waste treatment in regions and interactions between stakeholders (Soltani, Sadiq, & Hewage, 2016).

In a study of MSW systems for Istanbul, Turkey, Corban et al. evaluated three MCDA methodologies to evaluate potential systems (TOPSIS, PROMETHEE I, and PROMETHEE II). The study evaluated eight potential systems based on seven criteria. Scenarios developed were based on experts' input, and criteria were developed based on literature review and interviews with experts. The use of evaluating three MCDA methods (TOPSIS, PROMETHEE I and PROMETHEE II) showed that there was the ability to show consistency in their use. A limitation of this work, however, was due to the heavy use of experts in the evaluation of the systems. Also, it was recommended that sensitivity analysis be used to see how robust the results are for different ranges of parameters (Coban, Firtina Ertis, & Cavdaroglu, 2018).

Some limitations exist in the use of LCA to evaluate environmental systems. Environmental systems are complex and challenging to evaluate from a single point of view (Munda, 2004) due to system unknowns during the planning stages of a system. For example, when evaluating end of life waste management systems, environmental impacts can be determined through use of LCA, yet there is it is difficult to use results for a straightforward comparison of environmental impacts. LCA results may not be straight forward to understand because of differences in units and orders of magnitude (Zanghelini et al., 2018). Additionally, LCA cannot comprehensively rank the environmental impacts and does not provide an easy way to integrate the results into a decision-making process (Tsang et al., 2014). To improve LCA's effectiveness for environmental systems planning, LCA needs to be integrated with a complimentary decision-making process.

MCDA integration with LCA aids in environmental impact interpretation (Zanghelini et al., 2018), and evaluate multiple criteria through stakeholder input. Criteria to consider in environmental systems decision-making include distribution of cost and benefits, safety, minimization of risk, reliability, productivity, human values, benefit to community, etc. (Achillas et al., 2013; Choi, Nies, & Ramani, 2008; Hajkowicz, 2007; Kiker et al., 2005). A balanced evaluation must occur to prevent one criterion from being overshadowed by another (Giddings et al., 2002). For example, in end of life waste management system evaluation, the environmental criterion needs even consideration with economics or social criteria. The Analytical Hierarchy Process (AHP), an MCDA methodology, allows for the methodical evaluation of multi-criteria assessment in an organized manner (Contreras, Hanaki, Aramaki, & Connors, 2008) through diverse stakeholder input. Integrated LCA-AHP methodology needs development to aid in environmental systems evaluation of diverse criteria and allow for diverse stakeholder interaction.

Limitations in LCA-AHP integration exists such as limited data availability to allow for the completion of cradle to grave evaluation requiring the system boundaries (Teh, Tan, Aviso, Proentilla, & Tan, 2019). System simplification, such as gate-to-grave boundary definition, is needed to reduce the time to complete the evaluation process life cycle stage reduction (Hur, Lee, Ryu, & Kwon, 2005). Also, calculated quantitative LCA results are not readily comparable due to differences in units, as when comparing one ton of concrete waste disposed of in a landfill with one ton of carbon dioxide emissions (Reza, Sadiq, & Hewage, 2011). LCA databases are developed for regions and may not be able to reflect local environmental impacts (Kolosz, Grant-Muller, & Djemame, 2013). AHP typically utilizes only expert engagement and neglects stakeholders who may be directly impacted by the decision being made (Huang & Ma, 2004; Pineda-Henson, Culaba, & Mendoza, 2002; Stypka, Flaga-Maryanczyk, & Schnotale, 2016; Teh et al., 2019).

Three main issues exist with the integration of LCA-AHP for environmental systems planning. First, uncertainty and data limitations may lead to incomplete and inconclusive LCA results (Reap, Roman, Duncan, & Bras, 2008). It is impossible to have enough quantitative data in environmental systems planning stages to fully characterize potential environmental impacts. Second, LCA lacks a mechanism to evaluate the calculated environmental impacts with other important criteria such as social and economic impacts and compare them to rank alternatives. Finally, environmental decision-making using LCA and AHP are often only completed by experts. Yet, a variety of stakeholders, such as regulators, technical experts, facility managers, and community members, may not be included in the decision-making process, even though they may be most affected by the decision outcome.

To improve and manage these limitations, Streamlined Life Cycle Assessment (SLCA) and AHP can be used for system development and evaluation along with stakeholders' engagement during the preliminary planning stage of environmental projects. The SLCA and AHP integrated framework served to overcome the challenges of limited data and preliminary.

The integrated framework allows for the use of environmental impacts to be assessed with additional criteria for the elicitation of stakeholders to evaluate alternatives. The contributions of this paper lie in the development of the SLCA-AHP framework and the application of the new approach for evaluating different end of life municipal solid waste (MSW) management alternatives in Nashville, Tennessee. Currently, the regional MSW landfill utilized by Nashville is scheduled to reach air space capacity in five to eight years. Because new facility permitting takes years, it is imperative that Nashville begins to evaluate the potential end of life MSW systems based on a variety of criteria and through stakeholder engagement.

LCA and AHP integration allows for the evaluation of environmental systems. AHP evaluates the attributes of an environmental impact by examining the LCA impact factors (abiotic depletion, global warming, human toxicity, photochemical oxidation, acidification, and eutrophication) (Milutinovic et al., 2017). In addition, This method can be used to evaluate additional criteria, either qualitative or quantitative, such as economic (future costs and benefits) and social (proximity to the residential area, workers' and neighborhood's safety, employment, affordability, public acceptability, and land use) (Soltani et al., 2016). For prioritization of waste management strategies, integrated LCA and AHP have been used to evaluate environmental and economic impacts (Stypka et al., 2016).

When time and data are limited, SLCA use can simplify the life cycle stages and environmental impacts, while AHP allows results to be ranked and compared against additional criteria to allow for prioritization of criteria and identify the most preferred alternative (Ekener, 2016). Prior work involving integrated SLCA and AHP evaluated manufacturing processes, where a six by six matrix instead of the ERPA five by five matrix, allowing for the identification of process improvement by assigning weights to different life cycle stages. AHP was used to compare the life cycle stages and environmental impacts (Eagan & Weinberg, 1999). However, to fully understand the system, additional criteria should be considered, such as manufacturing process cost, workers' safety, and operational considerations to further assess the best alternative.

Unlike database informed LCA, integrated SLCA-AHP requires input from all important stakeholders such as experts, residents, and civic organization members who have a stake in the decision-making process (Lahdelma & Hokkanen, 2000). Yet, some recent SLCA-AHP studies relied only on experts without providing important additional stakeholder input from industry and community members (Huang & Ma, 2004; Pineda-Henson et al., 2002; Stypka et al., 2016; Teh et al., 2019). In order to provide an inclusive evaluation, participants need to include researchers, practitioners, the public, and other important stakeholder groups, since they may be the ones directly affected by the outcome of the evaluation process (Chifari et al., 2017). This research proposes to SLCA to allow stakeholders from diverse backgrounds to provide their preferences as input to the integrated framework based on the outcome of SLCA.

Conclusion

Based on the literature review, there is substantial documented use of LCA and MCDA in conjunction to evaluate environmental systems. Additionally, MCDA can be integrated into the goal and scope phase of the LCA process to allow for the development of the system and scope to be evaluated. SLCA can be applied instead of the Full LCA to allow for evaluation during the planning stages for environmental decision-making. Yet, there is a need to develop a methodology that can support the use of these tools by multiple stakeholders with diverse interests, perspectives, and technical backgrounds. The next chapter discusses the development of an integrated LCA-SLCA methodology to evaluate environment decision-making problems.

CHAPTER III

Evaluation of Full and Streamlined Life Cycle Assessments

Introduction

This chapter provides a discussion on Life Cycle Assessment (LCA) and Streamlined Life Cycle Assessment (SLCA). LCA use in environmental systems evaluation is discussed and is then applied to evaluate environmental impacts for end of life MSW systems for Metro Nashville. This chapter also discusses the SLCA for application to environmental systems evaluation. For comparison, SLCA is also applied to evaluate the environmental impacts end of life MSW for Metro Nashville. This parallel analysis allows for the comparison of the two methodologies to assess if SLCA is an appropriate tool to use in place of SLCA for the evaluation of environmental systems for decision-making applications.

Full Life Cycle Assessment

As discussed in Chapter II, LCA is a comprehensive tool to evaluate environmental impacts, as well as energy impacts, from a product or environmental system. The LCA process is rigorous follow the guidelines established in the International Standards Organization standard ISO 14040 to provide an in-depth impact assessment. LCAs allows for the definition of a complete environmental system.

LCA is used in environmental systems evaluations by defining system boundaries clearly, calculating the impacts of materials and energy into and out of the system, and assessing potential tradeoffs. This process is intended to evaluate the product of an environmental system from cradle-to-grave (Vigon, 1993). It provides a temporal snapshot and is not intended to provide a dynamic system evaluation. Generic LCA methods require that all main inputs to a process are taken into account, as well as the additional processes and materials which feed into those processes. For example, LCAs can account for the mining of raw materials utilized in product manufacturing as well as the production of energy needed for processes within the life cycle (Horne, 2009).

The LCA process is divided into four distinct phases: Goal and Scope Definition, Life Cycle Inventory (LCI) Analysis, Life Cycle Impact Assessment (LCIA), and Interpretation, as shown in Figure 3.

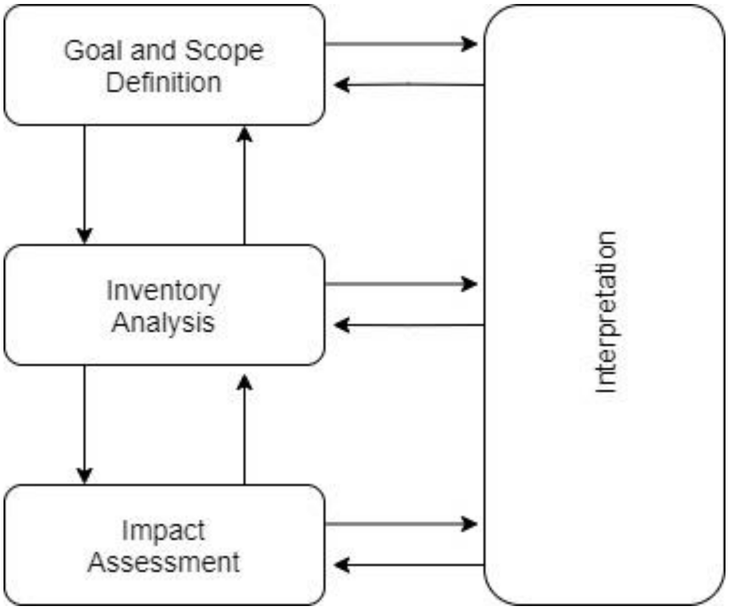

Figure 3: Stages of Life Cycle Assessment

Goal and Scope Definition includes the preliminary assumptions about the purpose of the study, the functional unit, and the system boundary, as well as the definition of the problem and system to be evaluated. LCI provides the material and energy inputs and outputs as produced waste that cross the system boundary between the environment and the process over the life cycle (Guinee, 2002). LCIA assesses the environmental impact of activity environmental impact indicators, such as air, water, and human health impacts, which arise from the product system. LCIA, which heavily relies on collecting the appropriate data based on the system's boundaries, is at the core of the LCA study. LCIA presents the results of the analysis for which all choices and assumptions are evaluated in terms of soundness and robustness. The main elements of the Interpretation step include the evaluation of results, for constancy and completeness, analysis of results, formulation of conclusion, and recommendations of the study with respect to the goal and scope of the study. The results can inform policy or stakeholders on the overall environmental impact from the process or system. Any step of the process can be reevaluated for refinement based on additional information or changes in system understanding, allowing for an iterative approach.

LCA's holistic nature is both a strength and a weakness. Though the LCA process intended to define all inputs and outputs, the evaluation process requires simplification to allow for modeling. There is a need to remove or minimize aspects of the system to allow for LCA evaluation. LCA is also limited by its inability to address localized impacts. Some aspects can be scaled down and regionalized for certain emissions, but the process does not reflect fully localized environmental impacts. Also, LCA evaluates a steady-state system rather than dynamic systems, and it regards all processes as linear processes (Guinee, 2002). The steady-state nature of LCA may minimize or neglect temporal operational changes, which cause variations in impacts.

Applications of LCA for Assessment of MSW Systems

LCA has been applied for the evaluation of MSW systems. The cradle-to-grave boundary is modified for MSW evaluations because raw material extraction or manufacturing of materials is not considered in the materials disposed of as MSW. The MSW system boundary begins at the point of disposal (when an item is no longer deemed useful) and follows the materials through transportation, processing, and final disposal or reuse. Hence the traditional definition of “cradle” does not apply (Cleary, 2009). The definition of “grave” in MSW differs between studies. In MSW LCA studies, the end of life MSW management system in operation, typically including landfilling, is utilized as a baseline against to compare other scenarios against. The system is then modified with inputs and outputs to represent potential diversion strategies or end of life treatment methods for consideration.

LCA has been used in a variety of MSW applications. For urban and rural MSW systems in Delaware, LCA was utilized to evaluate the base case of landfilling against systems with more diversion by recycling, composting, and water to energy. The study evaluated scenarios for tradeoffs for cost, materials diversion, and environmental performance. The study found that diversion and end of life strategies are community-specific and can have great variation between high population urban areas and low population rural areas. The study found that while quantitative and systematic approaches are useful in the MSW systems evaluation, there are decisions requiring subjective considerations such as diversity of stakeholders, political agendas, and public acceptance (Kaplan, Ranjithan, & Barlaz, 2009). In another study, landfilling without biogas recovery was the study baseline. Alternatives evaluated included landfilling using additional combinations of unit processes such as material recovery facility, composting, and incineration. The systems’ environmental impact was assessed. No tradeoffs were evaluated, though it is recognized that high investment and operation costs may affect environmental sustainability (Suna & Yay, 2015).

For MSW systems in Asturias, Spain, landfilling, incineration, and biomethanization were assessed. In addition to the evaluation of the impacts of human health, global warming, and ecosystem quality, the study evaluated resource depletion, such as non-renewable energy (crude oil) and mineral extraction. Results showed that traditional landfilling produces the greatest environmental impact. Transportation processes using fossil fuels produced a significant environmental impact. The sorting of the mixed waste fraction and the organic fraction reduced impacts due to reduced emission by replacement of raw materials, promoting environmental benefits (Fernández-Nava, del Río, Rodríguez-Iglesias, Castrillón, & Marañón, 2014). LCA was conducted on MSW fast pyrolysis to produce bio-oil in North Carolina and did not consider a comparison against other MSW end of life management systems (Wang, Wang, & Shahbazi, 2015).

LCA can look at specific MSW streams, such as food waste and sewage sludge. In Melbourne, Australia, the MSW streams were evaluated first to treat materials separately, with food waste being managing at a landfill and sewage sludge managed at a wastewater treatment plant, which represents current operations. Then simultaneously treating both materials by anaerobic co-digestion was evaluated, which was shown to have less environmental impact scope (Edwards, Othman, Crossin, & Burn, 2017).

Life Cycle Assessment Software

Commercially available LCA tools, such as OpenLCA, SimaPro, GaBi, are available to evaluate a product or environmental system from cradle-to-grave (Jain, Dyson, Tolaymat, & Ingwersen, 2015). MSW-LCA evaluations do not cradle-to-grave systems; therefore, modifications to the evaluation process must be considered. Additionally, the regionality of the software is important to tailor the evaluation to a specific region/location. Also, MSW consists of a variety of materials which are binned into generic categories (paper, plastic, organics, etc.). Typical LCA software is not well suited for these applications. Several MSW LCA software tools have been developed including Waste Reduction Model (WARM), MSW Decision Support Tool (MSW-DST), and Solid Waste Optimization Life-Cycle Framework (SWOLF) as shown in Table 5 which are better suited to assess LCA of end of life MSW systems (Jain et al., 2015). These software applications can evaluate the characteristics of waste better, since MSW can be broken into distinct categories such as paper, organics, metals, etc.

Table 5: LCA Software Application for End of Life MSW System Evaluation

Software	Application	Source
MSW-DST	MSW end of life management options for the State of Delaware	Kaplan et al., 2009
GaBi	Compare pyrolysis to existing end of life MSW systems in North Carolina	Wang et al., 2015
SimaPro	Compare composting and anaerobic digestion as the end of life management systems in Italy	(Di Maria & Micale, 2014a)
SimaPro	MSW options in Spain	Fernández-Nava et al., 2014
SimaPro	aerobic co-digestion of municipal food waste and sewage sludge in Australia	Edwards et al., 2017
SimaPro	MSW end of life evaluation in Turkey	Suna & Yay, 2015

MSW-DST is considered for use in the LCA evaluation for several reasons, such as its ability to be tailored to regional and US-specific electrical grid utilization and recycled materials pricing. If limited information is known during system evaluation, the software default operational values that can be used. The software also optimizes operational aspects to minimize economic, energy, and environmental impacts. Additionally, MSW-DST software is tailored for use in the

United States and allows for inputs to be adjusted to reflect unique regional operational parameters, such as electrical grid utilization and recycled materials pricing.

Life Cycle Assessment Impact Categories

The LCIA considers impact categories such as climate change, ozone depletion, eutrophication, acidification, human toxicity, ionizing radiation, ecotoxicity, photochemical ozone formation, land use, and resource depletion. The emissions from system processes are assigned to each of these impact categories and converted into indicators using impact assessment models. Emissions and resources consumed, as well as different product options, can then be cross-compared in terms of the indicators (European Commission - Joint Research Centre - Institute for Environmental and Sustainability, 2010). Regional environmental impact categories have been developed for Europe and the United States. Databases can be utilized with LCA software for LCIA assessment. The Center for the Environmental Science of Leiden University, the Netherlands, impact assessment (CML-IA) utilizes ten baseline impact categories that include depletion of abiotic resources, climate change, stratospheric ozone depletion, human toxicity, fresh-water ecotoxicity, marine ecotoxicity, photo-oxidant formation, terrestrial ecotoxicity, acidification, and eutrophication. These impact assessment categories are utilized across the world for LCA evaluation in Australia (Edwards et al., 2017), the United States (Wang et al., 2015), Italy (Di Maria & Micale, 2014b), London, England (Al-Salem, Evangelisti, & Lettieri, 2014), and Turkey (Suna & Yay, 2015). In some cases, software comes prepopulated with specific impact categories, such as with MSW-DST (ISWM-DST) which tracks 30 air-and water-borne pollutants and optimizes on seven air pollutants (carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), nitrogen oxides (NO_x), sulfur oxides (SO_x), particulate matter (PM), and greenhouse gas equivalents (GHEs)) (Kaplan et al., 2009). Other studies combine impact categories, (IMPACT 2002, Eco- Indicator 99, CML, and IPCC), to evaluate the impacts such as resource depletion (Fernández-Nava et al., 2014).

Life Cycle Assessment for End of Life Municipal Solid Waste Management

LCA was applied to evaluate the environmental impacts of MSW end of life systems for Metro Nashville. In 2017, Metro Nashville implemented a zero waste master plan to divert 90% of disposed of materials from landfills over 30 years to reduce its dependence on landfills (CDM Smith, 2016). Metro Nashville had an estimated population of 684,410 in 2016, with a 9.2% growth from 2010 (United States Census Bureau, 2017). With the advent of economic growth in the area, the population is projected to continue increasing which will make meeting zero waste goals challenging

Many United States communities, such as Austin, San Francisco, California, Fort Collins, Colorado, and Middletown Connecticut, are developing plans to achieve zero waste goals for their communities (United States Environmental Protection Agency, 2017). The Zero Waste International Alliance defines zero waste as "a goal that is ethical, economical, efficient and visionary, to guide people in changing their lifestyles and practices to emulate sustainable natural cycles, where all discarded materials are designed to become resources for others to use (Zero Waste International Alliance, 2015)." However, the definition of zero waste is unique to each community and its specific conditions. To aid in achieving zero waste, a hierarchy of materials management was developed to identify "waste diversion" (recycling and composting) and "waste to energy" production as more preferable than landfilling to manage waste. (United States Environmental Protection Agency, 2017).

Regardless of a community's plan to implement zero waste goals, a percentage of remaining waste that remains and cannot be recycled, composted, or reused must be managed. LCA can be utilized to aid in finding the end of life MSW system, which will help reduce environmental impact. An LCA is performed to consider what end of life MSW systems could be implemented by Metro Nashville to reduce the environmental impact of any

Metro Nashville Current Conditions

Metro Nashville's MSW system consists of onsite collection, convenience centers, transfer stations, and landfill disposal. Additionally, recycling (comingled and single-stream), bulk waste (white goods), and bulk yard waste are collected. Residential and commercial collection is performed by Metro Nashville Public Works and private contractors. For residential properties, solid waste is collected weekly, comingled recyclables are collected monthly, and bulk yard waste is collected quarterly. Bulk waste is collected as requested. Commercial solid waste and recycling collection vary by facility and location. Four convenience centers are located within the Metro Nashville for residential drop-off of household waste and recyclables. Commercial disposal is prohibited at convenience centers.

Metro Nashville MSW is taken to one of two transfer stations to consolidate waste from collection vehicles for placement in high-volume trailers for transport to landfills (CDM Smith, 2018). Transfer stations provide an economical means to transport waste to distant disposal sites and are not intended for long term storage of waste materials (United States Environmental Protection Agency, 2002). All MSW from Metro Nashville is disposed of in Class I (MSW) landfills, which are engineered facilities designed to protect the environment by meeting state and federal regulations (United States Environmental Protection Agency, 2017). Collected recyclables are processed at a materials recovery facility (MRF) where recyclables are sorted and transported for reuse and remanufacture. Metro Nashville utilizes one MRF (CDM Smith, 2018).

MSW Characterization

A waste and recycling study was conducted by Metro Nashville to evaluate the composition of disposed of materials generated was performed in 2017. For MSW, 42,136 pounds from 192 waste sources (split evenly between residential and commercial) were analyzed for summer and fall of 2017, with composition shown in Figure 4 (CDM Smith, 2018). Thirty percent of the landfilled MSW contained recyclable materials (papers, plastic, glass, and metals) and almost 23 percent organics, which can be diverted from landfill disposal.

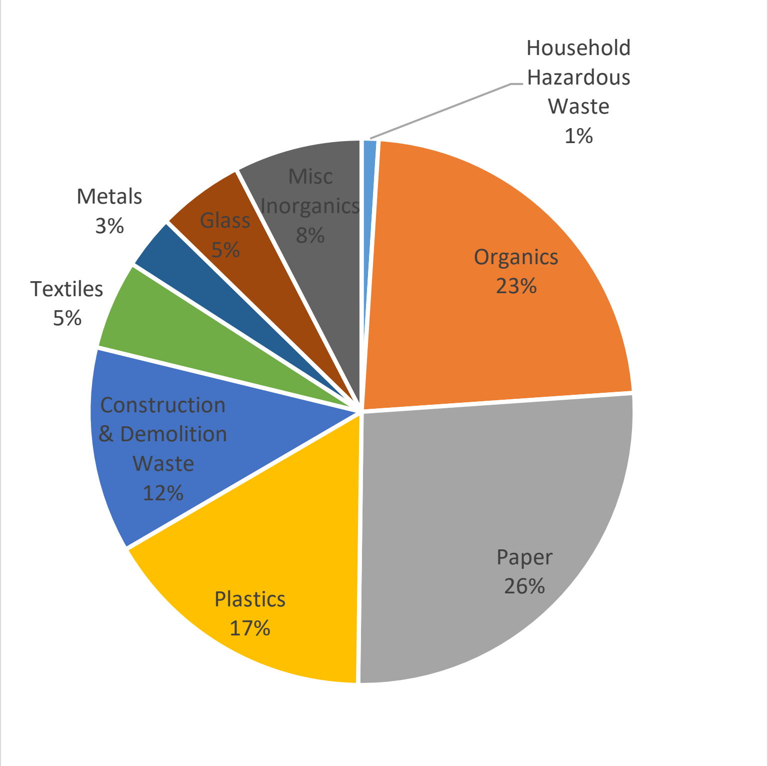

Figure 4: Composition of Combined Residential and Commercial Waste

For recyclable materials, 93 samples were analyzed for two seasons, as shown in Figure 5. Forty samples were from commercial generators, and 53 samples were from residential generators. Paper accounted for 78 percent of materials recycled, with the majority being attributed to cardboard boxes (CDM Smith, 2018). Though materials are diverted from MSW to recycling, material reuse may be based on quality, economics, or material needs for manufacturing and reuse. Also, to aid in reuse, recycled materials must be easily separated and not contaminated with other materials.

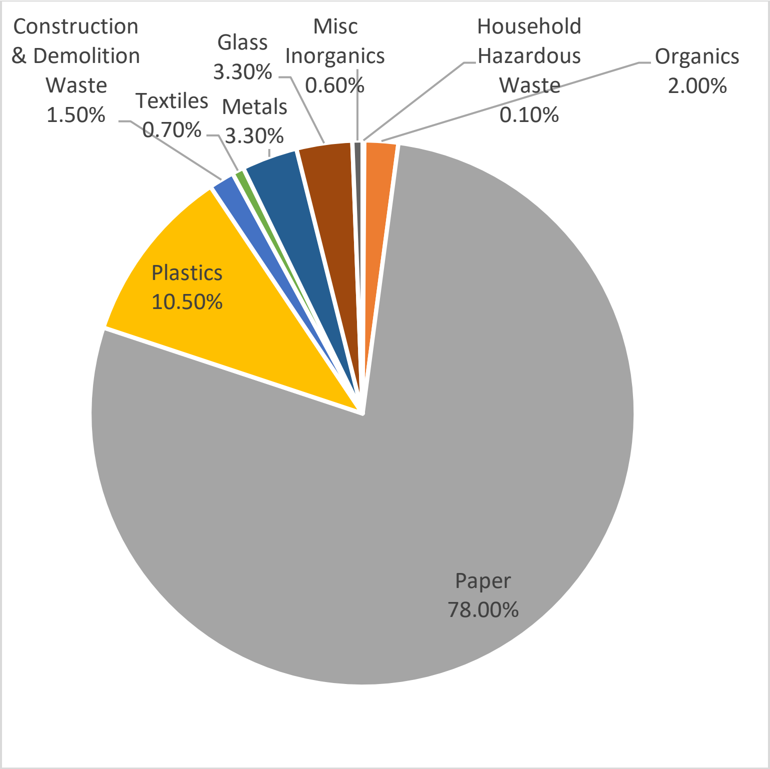

Figure 5: Composition of Recovered Residential and Commercial Materials

Goal and Scope

The goal of the LCA is to evaluate and compare the environmental impacts on the potential end of life management of MSW to evaluate environmental impacts and to inform the zero-waste plan for Metro Nashville. The geographical system boundary evaluated is Metro Nashville, which includes all of Davidson County. Metro Nashville sends all waste disposed at three landfills within Middle Tennessee Region. The landfill that accepts the majority of Metro Nashville's waste landfill is expected to close within the next five to ten years. The LCA will inform Metro Nashville on the environmental and economic impacts of the potential end of life MSW technologies to select an MSW system with the least environmental impact. The functional unit for this study is one ton of MSW.

Metro Nashville MSW boundary is shown in Figure 6 begins at the point of residential and commercial disposed of MSW, recyclables, or green waste. Generation sources include single-family residential, multi-family residential and commercial sites. The residential generation rate estimates are 4.8 pounds per person per day. The 2016-2017 estimated population is 687,889 people in 274,187 households. It is estimated in Metro Nashville that 40 percent of households are multifamily, and 60 percent are single-family (Mccullough, Cole, Harris, & Mansa, 2017). It is estimated there are 18,619 commercial units with a generation rate of 768 pounds/unit-week (Nashville Chamber of Commerce, Business Climate, US Census Bureau, 2014).

The single-family residential waste is collected from curbside containers or be dropped off at regional convenience centers. The multi-family residential and commercial waste is collected from large bins, dumpsters, or compactors. Metro Nashville's MRF sorts recyclable materials from waste. Green lines represent the movement of MSW destined for final landfilling. Blue lines represent recyclable materials, either commingled or separated at the MRF and destined for future recycling/reuse. Red lines represent MSW and waste from the MRF, which is landfilled. Yellow lines represent yard waste and organics, which are composted at commercial composting facilities. The purple line from composting represents a reusable material. Transportation after initial disposal can occur by either a personal vehicle or a garbage truck. Convenience center bulk materials are transported in bulk trailers to transfer stations for disposal at a landfill.

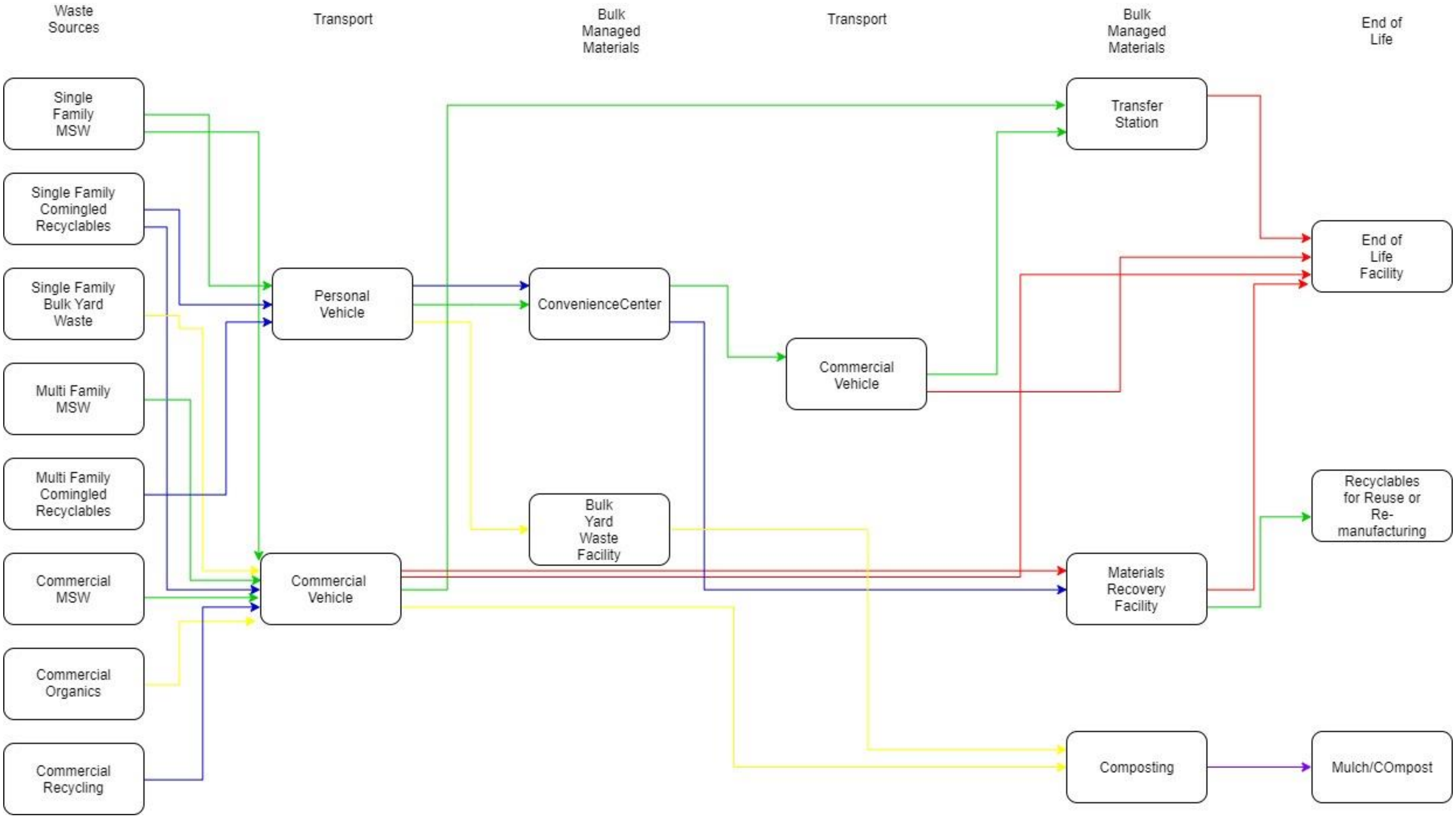

Figure 6: Current Metro Nashville MSW System

Scenarios

To facilitate the LCI analysis evaluation, the MSW system was simplified, as shown in Figure 7. This figure is designated as Scenario 1 and served as the baseline for current Metro Nashville MSW management. The LCI analysis begins at the point of material disposal with system inputs of MSW, recyclables, and yard waste. Additional system inputs are shown in purple. Transportation is simplified in the model to assume all waste is handled by garbage trucks or bulk vehicle. Personal vehicles were excluded due to limited data on personal vehicle movement of disposed of materials within the system boundary. The red lines represent waste destined for final landfill disposal, which does not leave the system boundary. Blue lines represent recycled materials, and green lines represent compostable materials. System outputs include recovered materials (recyclables and mulch), as well as emissions to air, land, and water, as well as the potential for energy production.

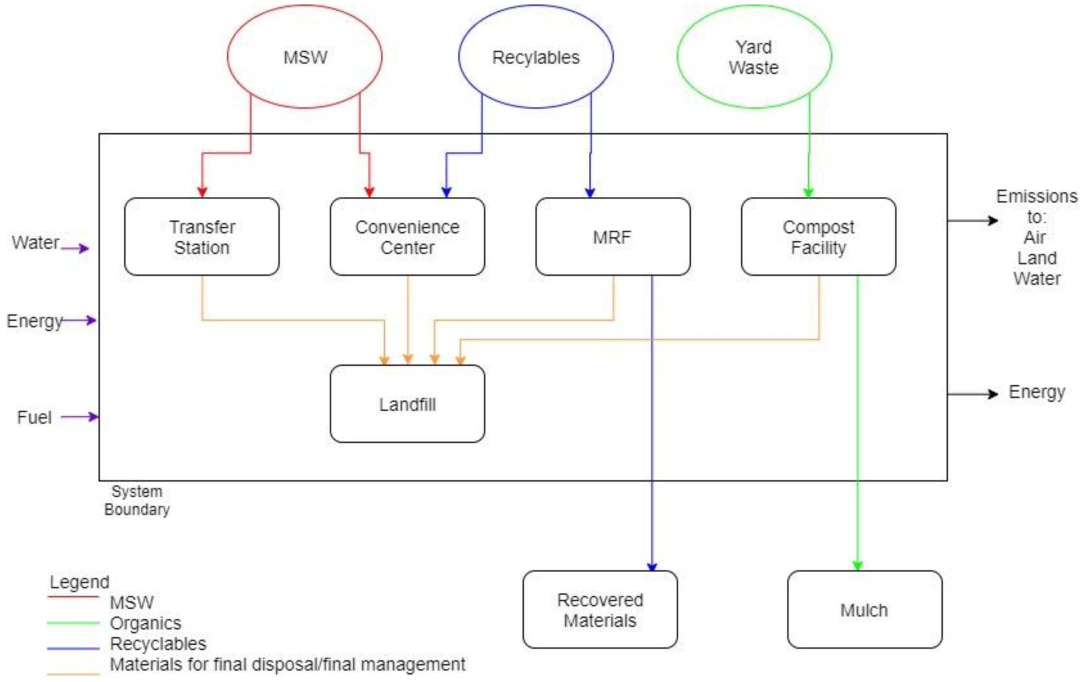

Figure 7: Scenario 1: Landfilling

Two additional end of life MSW management systems were evaluated and were selected based on technically feasible and available technologies not currently implemented on a commercial scale in Tennessee based on the zero-waste hierarchy but are implemented in the United States. Because of the high organic composition of Metro Nashville MSW, MSW composting was selected for consideration. Any non-compostable materials would be disposed of in a Class I landfill. Additionally, the presence of organics and other energy-containing materials presented an opportunity to evaluate the implementation of a waste to energy facility. Historically, Metro Nashville operated an incineration facility in the 1970s and 1980s. MSW was incinerated, and ash produced from combustion was disposed of in ash monofill landfills in the region.

As discussed, three scenarios are evaluated for Metro Nashville:

- Scenario 1: Landfilling
- Scenario 2: Waste to Energy
- Scenario 3: MSW Composting

Scenario 1: Landfilling

Scenario 1 represents the baseline scenario where landfilling is utilized for end of life management system for Metro Nashville, as shown in Figure 7. Recyclables are managed at the MRFs, and bulk yard waste is composted and mulched. The transport of recyclables for further processing is not included in this study as it is outside the boundaries. End of life MSW treatment is achieved by landfilling, and it is assumed that the landfill is 30 miles away from the transfer station. Landfill leachate is collected and treated before discharge to surface water, and landfill gas is collected, treated by a flare for 40 years, and discharged to the atmosphere. Additional system information for this scenario is presented in Table 6.

Table 6: End of Life MSW Scenarios

Scenario	Residential Collection	Multi-Family Collection	Commercial Collection	Transfer Stations	MRF	Treatment	Disposal
1. Landfilling	Collection of Mixed MSW, Commingled Recyclables Sorted at MRF, and Yard waste Recyclables Drop-Off	Collection of Mixed MSW Recyclables of Drop-off	Collection of Mixed MSW and Presorted Recyclables	Transfer of Mixed MSW	Commingled recycles, and presorted recycles sorted at MRF	Yard waste	Distance to landfill 30 miles, 40 years of flare use for landfill gas, then vent
2. Waste to Energy	Collection of Mixed MSW, Commingled Recyclables Sorted at MRF, and Yard waste Recyclables Drop-Off	Collection of Mixed MSW Recyclables of Drop-off	Collection of Mixed MSW and Presorted Recyclables	Transfer of Mixed MSW	Commingled recycles, and presorted recycles sorted at MRF	MSW Waste to Energy and Yard waste	Distance to landfill 30 miles, 40 years of flare use for landfill gas, then vent
3. MSW Composting	Collection of Mixed MSW, Commingled Recyclables Sorted at MRF, and Yard waste Recyclables Drop-Off	Collection of Mixed MSW Recyclables of Drop-off	Collection of Mixed MSW and Presorted Recyclables	Transfer of Mixed MSW	Commingled recycles, presorted recycles sorted at MRF and Materials Recovery Front-end before Mixed MSW Compost	MSW Composting and Yard waste	Distance to landfill 30 miles, 40 years of flare used for landfill gas, then vent

Scenario 2: Waste to Energy

This scenario, shown in Figure 8, involves the use of waste to energy facility processes MSW treatment. Waste to energy allows for the incineration of waste to produce energy. A reduction in waste volume occurs, and residuals (ash) are landfilled in an ash monofill landfill. Recyclables and green waste are managed in a similar way to Scenario 1. Any waste materials are disposed of in a Class I landfill as appropriate. Landfill leachate is collected and treated before discharge. Landfill gas is collected, if necessary, treated by a flare for 40 years, and discharged to the atmosphere. Materials are assumed to be transported 30 miles for disposal in MSW and ash landfills.

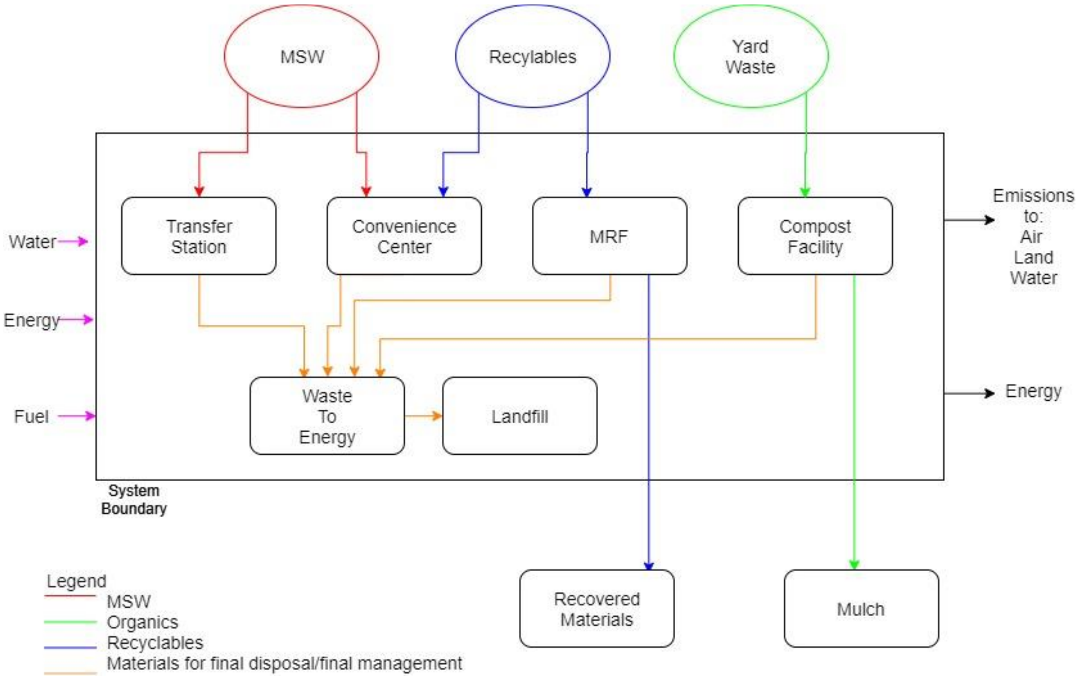

Figure 8: Scenario 2: Waste to Energy

Scenario 3: MSW Composting

Scenario 3, shown in Figure 9, involves the use of MSW composting facility for the treatment of organics (shown in red). Residuals from composting are placed in an MSW landfill. Landfill leachate is collected and treated before discharge. Landfill gas is collected, treated by a flare for 40 years, and discharged to the atmosphere. Materials are assumed to be transported 30 miles for disposal in MSW and ash landfills. Additional system information for this scenario is presented in Table 6, where model inputs are shown.

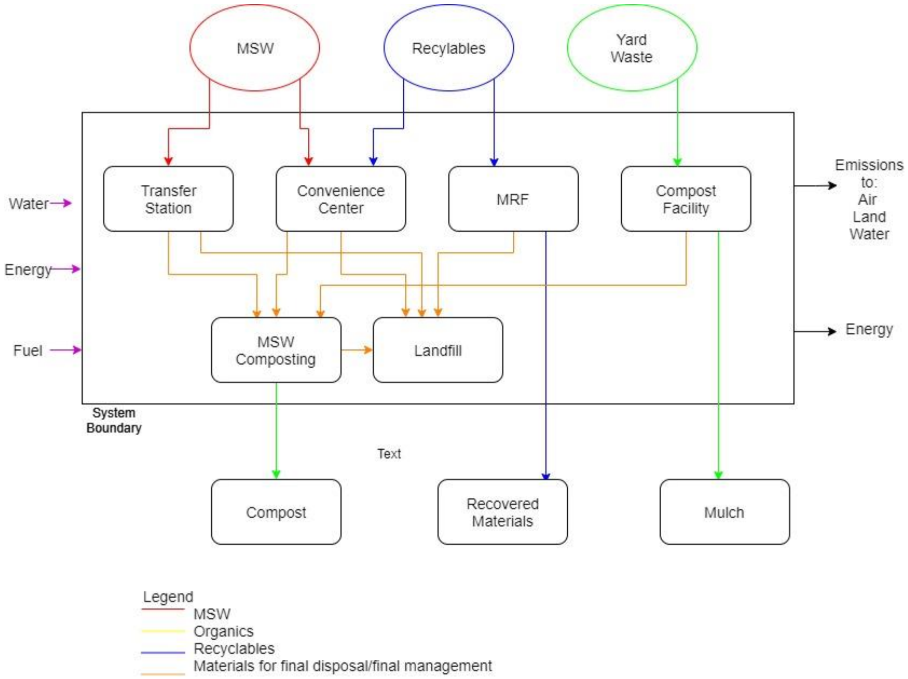

Figure 9: Scenario 3: MSW Composting

Life Cycle Inventory Analysis

The LCI analysis involves the collection of data and calculation to quantify relevant inputs, such as resource use, and outputs, such as releases to air, water, and land, related to the end of life MSW technology. The analysis is iterative and can be refined as additional information on systems and boundaries are evaluated. MSW-DST Version 1.0 (2017) is utilized in the United States based LCI analysis. Developed in 1994, it can be used to evaluate the economic and environmental aspects of MSW operations, while allowing for optimization for cost, energy, and CO_2 emissions. The tool allows for the classification of 39 waste materials, such as glass, plastic, and metal. MSW-DST calculates energy consumption, greenhouse gas emissions, criteria air pollutants, and releases to water (Jain et al., 2015).

The three evaluated scenarios are presented in Figure 7, Figure 8, and Figure 9. MSW-DST considers the movement of MSW, recyclables, and yard waste from waste collection, transportation (personal and commercial), and management at the end of life facility by both, but does not account for the manufacturing of the collection vehicles, collection bins, equipment used in processing, etc. An MRF processes and separates comingled and source-separated recyclables such as aluminum, glass, paper, plastic, and steel for recovery and reprocessing. The reuse of recovered recyclable materials is not evaluated in this LCI analysis. Composting involves the processing of organic material to form compost and mulch. For the LCI analysis, two types of composting are considered: mixed municipal composting and yard waste composting. Waste to energy involves the combustion of waste to produce electricity. Ash is disposed of in an ash monofill landfill, and any remaining MSW is disposed of in a Class I landfill. Bulk transport trucks are used to move materials between facilities. Environmental emissions are calculated for air, water, and solid waste for each step (Research Triangle Institute Center for Environmental Analysis, 2000).

Life Cycle Impact Assessment

The LCIA step involves calculating annualized cost, energy consumption, and environmental emissions for the three scenarios. Environmental impacts are assessed using TRACI (Tool for the Reduction and Assessment of Chemical and other Environmental Impacts) characterization factors (Jain et al., 2015). Characterization factors quantify the potential impacts that inputs and releases have on specific impact categories in common equivalence units (Bare, 2011). The environmental impact categories evaluated in by MSW-DST are shown in Table 7.

Table 7: Evaluated Impact Categories and Indicators

Impact Category	Indicators
Global Warming	Carbon dioxide - fossil, methane, nitrogen oxides, sulfur oxides, ammonia (air), hydrochloric acid
Human Health Cancer Air	Lead – air
Human Health Noncancer Air Point Source	Total particulate matter, nitrogen oxides, sulfur oxides
Eutrophication Air	Nitrogen oxides, ammonia
Eutrophication Water	Biological oxygen demand (BOD), chemical oxygen demand (COD), ammonia, phosphate
Ecotoxicity Air	Lead, ammonia
Ecotoxicity Water	Iron, copper, cadmium arsenic, mercury, selenium, chromium, lead, zinc
Smog Air	Nitrogen oxides, carbon monoxides, methane

MSW-DST software automatically optimizes operating conditions based on the user inputted information for cost, energy, and CO_2 production. The optimization module may reduce the use of unit operations, for example composting, to optimize the system’s operations (Research Triangle Institute Center for Environmental Analysis, 2000). The waste flow model communicates with the optimization module to search for optimal solutions from many possible MSW management strategies.

Metro Nashville is required to meet National Ambient Air Quality standards such as nitrogen oxides, ozone, particulate matter, and sulfur dioxide (MPO Nashville Area, n.d.). Additionally, Metro Nashville is located along the Cumberland River watershed, which is impacted by urban and agricultural land uses for nitrogen and phosphorus compounds (Kingsbury, Hoos, Woodside, & Survey, 1999). Therefore, the standard LCIA impact categories of Global Warming, Human Heath Air Point Source, Eutrophication Water, and Ecotoxicity Water are evaluated for Metro Nashville.

Results

The results of the LCIA for the three scenarios using MSW-DST are shown below. The MSW-DST software calculates the movement of mass between steps in each scenario, total energy usage, and environmental impact optimized for each scenario (Solano, Ranji Ranjithan, Barlaz, & Downey Brill, 2002).

Mass

The results of the movement of the material for each optimized for energy, cost, and CO_2 emissions for each scenario are shown in Figure 10. Each scenario was evaluated for cost, energy consumption, and environmental impact through LCIA and is normalized per the total mass of waste managed.

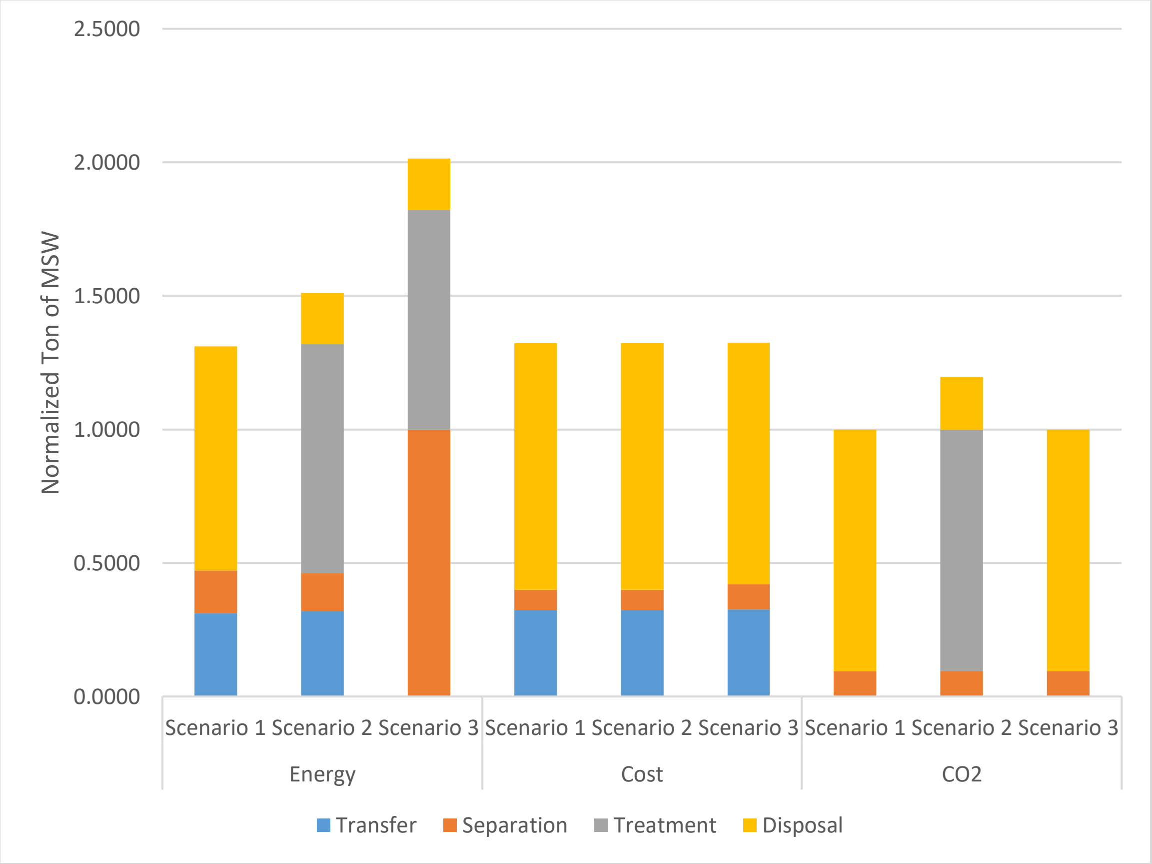

Figure 10: Mass Across Unit Processes Normalized per 1 Ton MSW

The individual breakdown of materials movement between unit processes for Scenario 1 is shown in Figure 11. In all scenarios, yard waste collection and composting are disregarded by the during optimization. Regardless of the optimized case, the approximate amount of MSW landfilled was the same, which means that negligible waste reduction occurred.

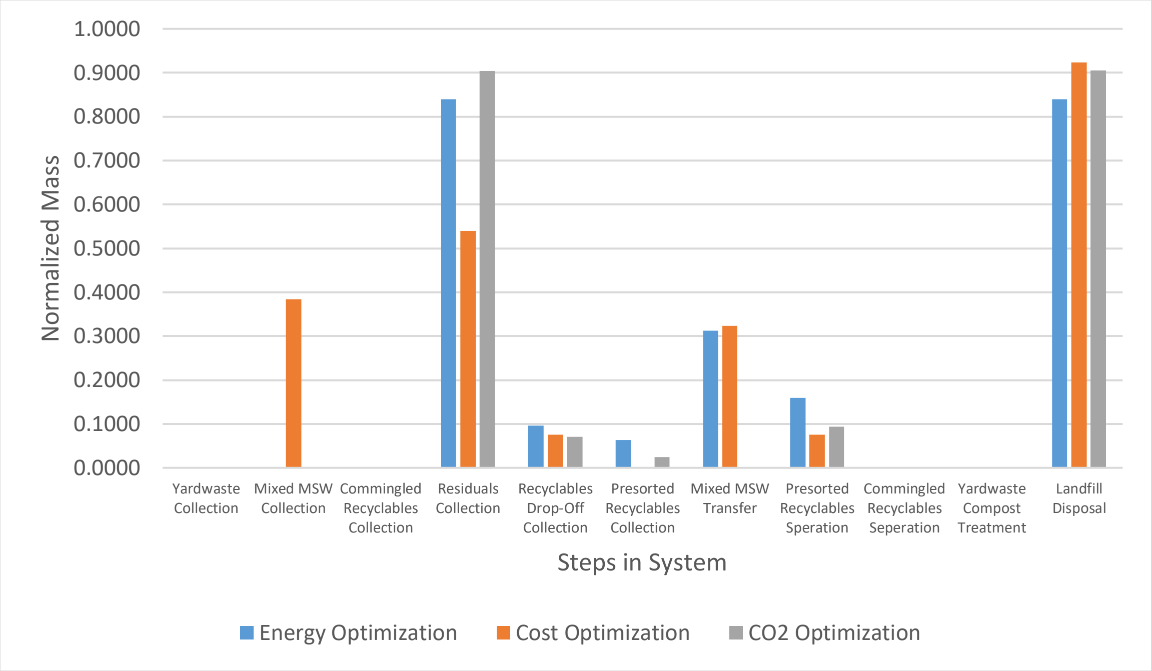

Figure 11: Scenario 1: Mass Transfer Between Processes Normalized for 1 Ton MSW

The individual breakdown of materials movement between unit processes for Scenario 2 is shown in Figure 12. Similar to Scenario 1, yard waste collection and composting are disregarded by the model during optimization. Landfilling all materials occur when the cost is optimized. For energy and CO_2 optimization, similar amounts of MSW are processed in the waste to energy facility. There was a great decrease in the amount of disposed waste when MSW was treated by waste to energy facility since the MSW organic fraction is converted to energy, and only the combustion residuals are disposed of in the landfill.

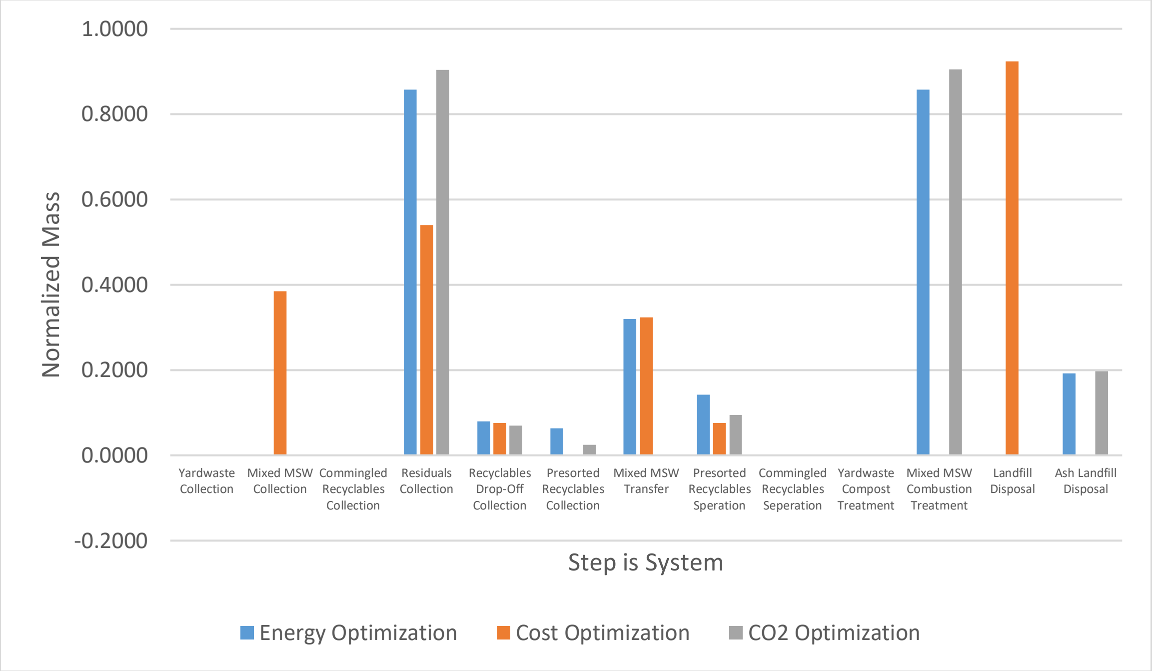

Figure 12: Scenario 2: Mass Transfer Between Unit Processes Normalized for 1 Ton MSW

The individual breakdown of materials movement between unit processes for Scenario 3 is shown in Figure 13. Similar to Scenario 1, yard waste collection and composting are disregarded by the model during optimization. Only in the case of optimization for energy was MSW processed in the mixed MSW composting system. Minimal landfilling was required for this scenario. When optimizing for cost and CO_2 emissions, landfilling was the optimal means to end of life MSW management. When optimizing for energy, there was a great decrease in the amount of mass landfilled since the MSW is converted to compost, which is a reusable material.

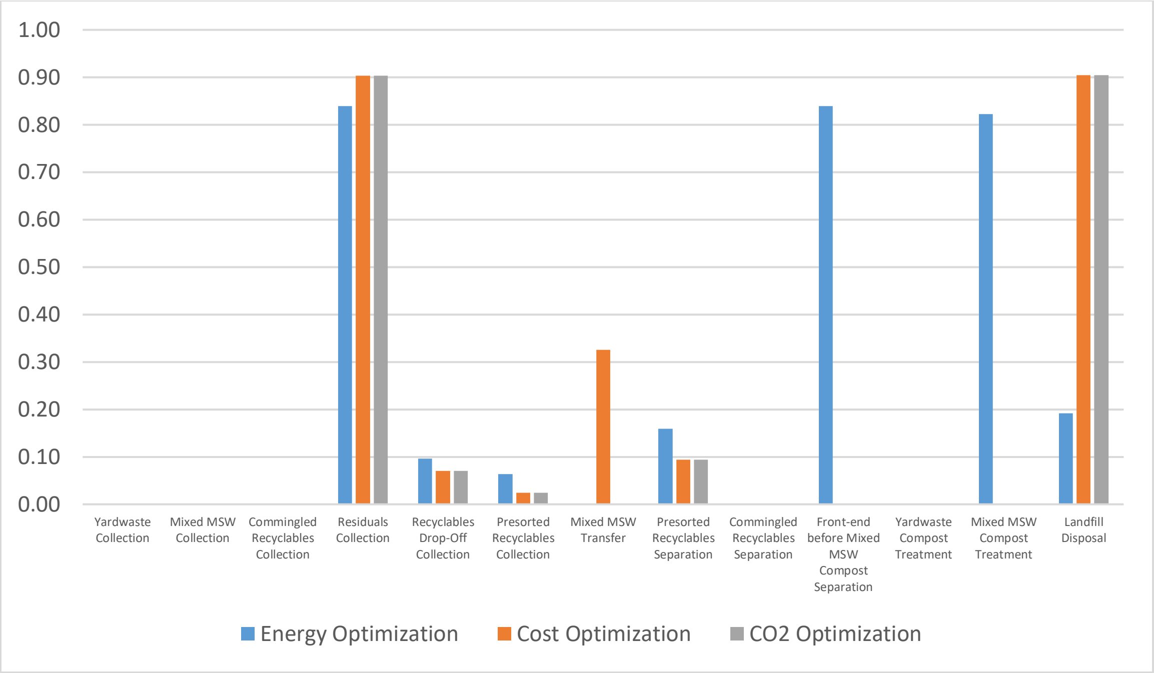

Figure 13: Scenario 3: Mass Transfer Between Unit Processes Normalized for 1 Ton MSW

Cost

MSW-DST calculated cost includes annual capital and annual operating costs optimized for each scenario. MSW-DST utilizes full cost accounting, which is a systematic approach for identifying, summing, and reporting the actual cost of solid waste management. EPA developed full cost accounting as a tool to compile detailed cost information for MSW operations and to communicate these costs to the public. Full cost accounting focuses on the flow of economic resources (assets) and accrues costs as resources are used or committed, regardless of when the money is spent (United States Environmental Protection Agency, 1997a). Default costing values in the software were used if information specific to Metro Nashville was unavailable. In the future, scenario costs can be further refined to include more specific capital and operational costs, as reported by Metro Nashville.

Figure 14 presents the annual cost to operate each scenario based on one ton of MSW processed. Operating costs range approximately from \$90 to \$160 per ton of MSW. Costs for all scenarios do not include comingled recycling. For Scenario 1, optimization for cost yields the lowest cost, while CO_2 optimization yielded the highest cost. For Scenario 2, optimization for cost yields the lowest cost, while CO_2 optimization yields the highest cost. For Scenario 3, optimization for cost yields the lowest cost, while energy optimization yields the highest cost.

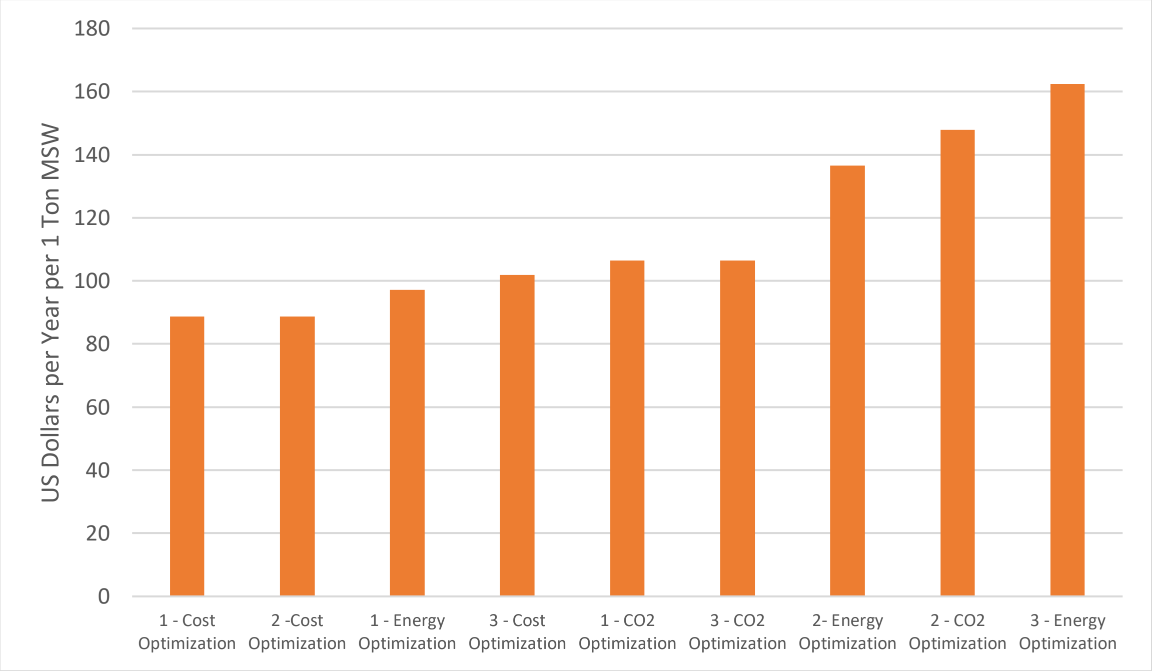

Figure 14: Cost Normalized for 1 Ton MSW

Energy

Figure 15 presents the energy consumption and production under each optimized scenario. All values are calculated as Million British Thermal Units (MMBTUs) based on one ton of MSW processed. All but two cases (cost-optimized cases for Scenario 1 and 2) have negative energy consumption, meaning energy is produced or recovered. Recycling and treatment of MSW can decrease the amount of energy utilized in MSW management. When optimized for energy and CO_2, Scenario 2 yields the maximum net negative energy consumption since it incorporates an energy production system, which offsets the energy consumed through fuel and electricity. Energy consumption for Scenario 1, optimized for energy and CO_2 emissions, is low because of recovered materials for recycling, which reduces raw material processing and provides energy savings. For Scenario 3, all optimized cases present similar energy results.

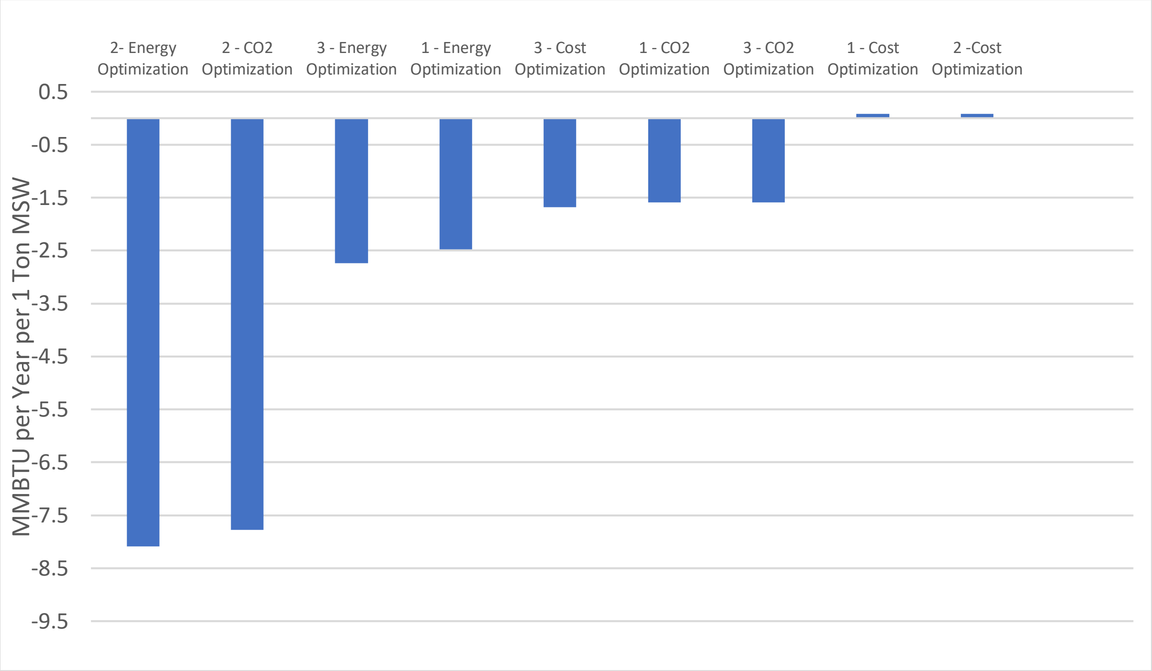

Figure 15: Energy Normalized for 1 Ton MSW

Global Warming

Figure 16 presents the global warming potentials (GWPs) from TRACI used to calculate the potency of greenhouse gases using CO_2 as the indicator (Bare, 2012). Methane and CO_2 are reported in kilograms (kg) per CO_2 equivalent normalized per 1 ton of MSW. MSW-DST provides results for each scenario for cost, energy, and CO_2. Scenario 2, when optimized for energy and CO_2, shows avoidance of methane and CO_2, as compared with landfilling or MSW composting. Landfilling and MSW composting are expected to create an increase in methane production as it is a byproduct of microbial degradation of organic materials.

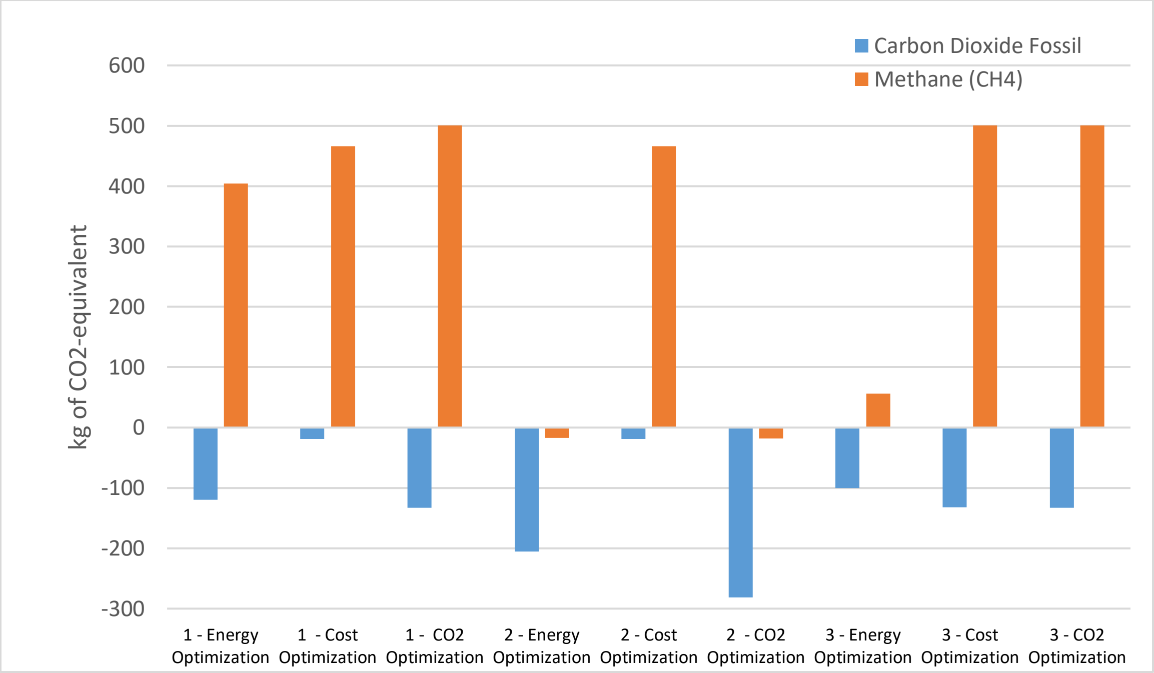

Figure 16: Global Warming Potential per 1 Ton of MSW

Acidification

Acidification is the increasing concentrations of the hydrogen ion (H^+) within an environment. Hydrogen ion formation is the result of the addition of acids such as sulfuric and nitric acids into the environment. The acidity of the environment can be due to chemical reactions or biological activity (Bare, 2012). SO_x, NO_x, ammonia, and hydrochloric acid (HCl) dissociate or react with the environment to cause increases of H^+. The indicator for these impacts is kg of H^+ moles-equivalent, as shown in Figure 17. These pollutants are typically formed during fuel combustion and electrical energy production and consumption. All scenarios show that CO_2, NO_x, SO_x, ammonia, and HCl formation potential is avoided. Scenario 2 shows the greatest avoidance when optimized for energy and CO_2.

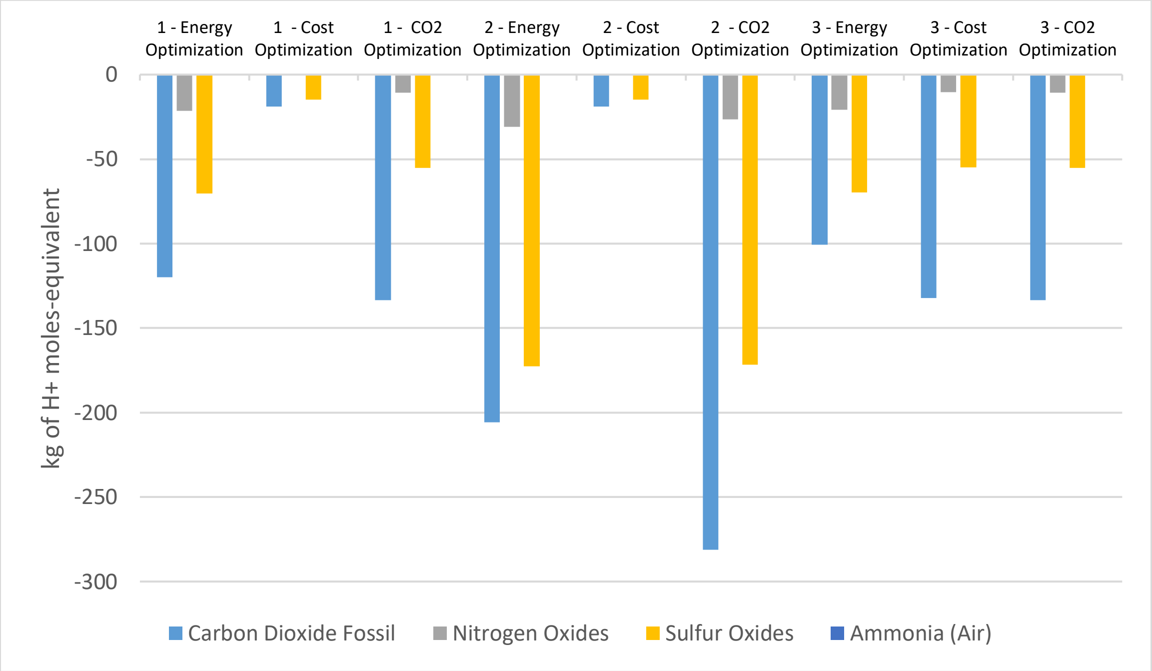

Figure 17: Acidification Potential for Air per 1 Ton MSW

Eutrophication

Eutrophication is the enrichment of an aquatic ecosystem with nutrients, such as nitrates and phosphates. The presence of these nutrients causes accelerated growth of the biological productivity of algae and weeds, which might adversely affect an aquatic ecosystem. Impacts to water from nutrients are caused by the presence of fertilizer runoff from agricultural lands (Bare, 2011). Calculated emissions for ammonia to water are shown in Figure 18. The remaining calculated eutrophication constituents for air and water are presented in Figure 19. NO_x, biological oxygen demand, ammonia, COD, and phosphate are presented using the indicator of units of kg of N-equivalents. Results with negative values indicate that there is a minimal avoidance of eutrophication potential. Scenario 2 for energy and CO_2 optimization has the least eutrophication impact potential.

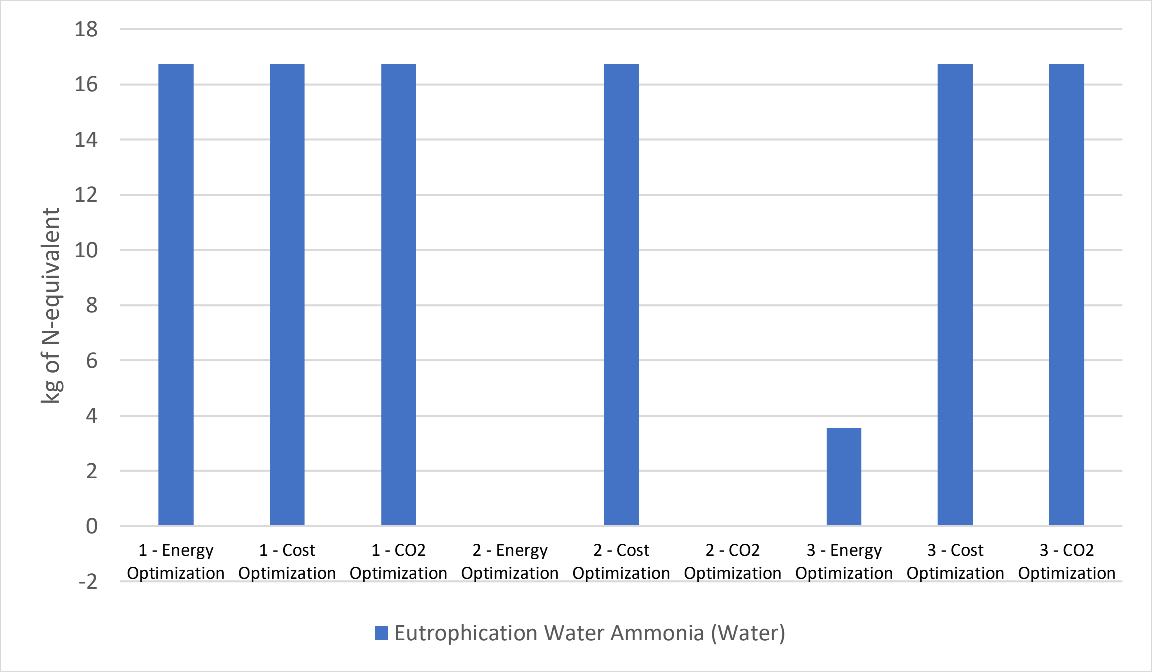

Figure 18: Eutrophication Potential from Ammonia (Water) per 1 Ton MSW

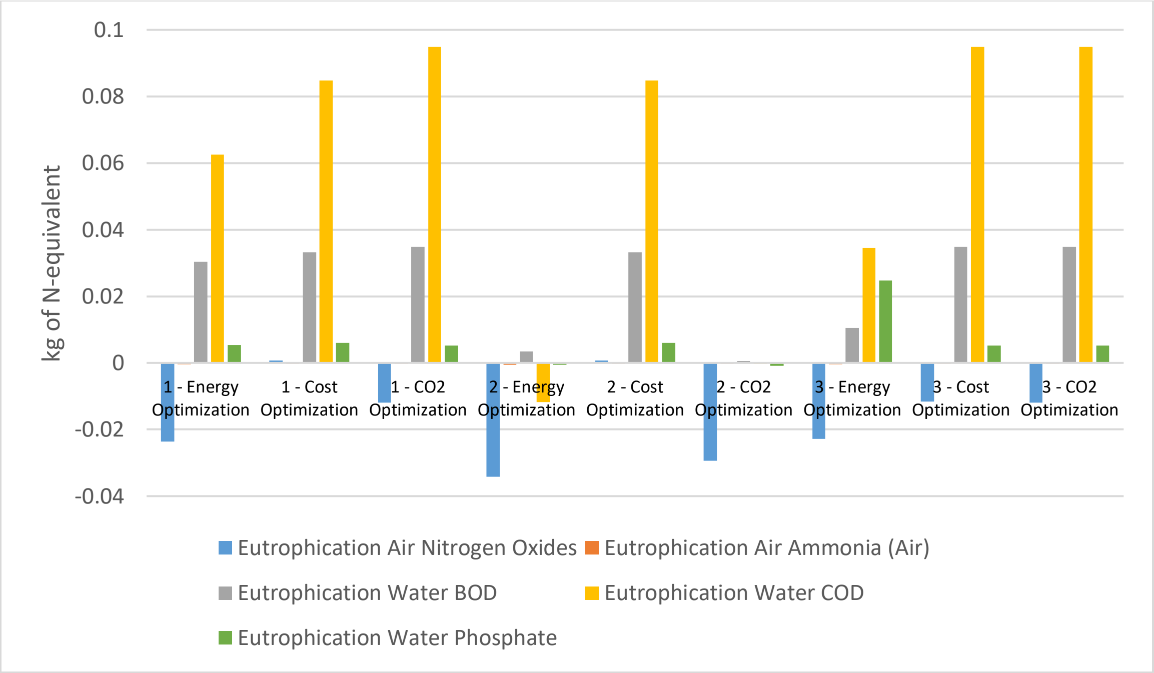

Figure 19: Eutrophication Potential from Air and Water per 1 Ton MSW

Smog

Ground-level ozone is created by various chemical reactions, which occur between NOx and volatile organic compounds (VOCs) in sunlight. Smog can affect the respiratory system, potentially increasing symptoms of bronchitis, asthma, and emphysema. Permanent lung damage may result from prolonged exposure to ozone, which is the cause of this chemical reaction. Ecological systems can also be impacted. The primary sources of ozone precursors are motor vehicles, electric power utilities, and industrial facilities (Bare, 2011). Smog is measured in terms of kg of ozone equivalent for NO_x, carbon monoxide, and methane, as are presented in Figure 20 and Figure 21. Ozone is an issue in Metro Nashville during the summer months as conditions heat up, and more cars travel through the area. Carbon monoxide formation was avoided in all scenarios. Scenarios 1 and 2 optimized for the cost caused the formation of both NO_x and methane. Scenario 2 optimized for energy and CO_2, and Scenario 3 optimized for energy showed avoidance for all smog formation constituents.

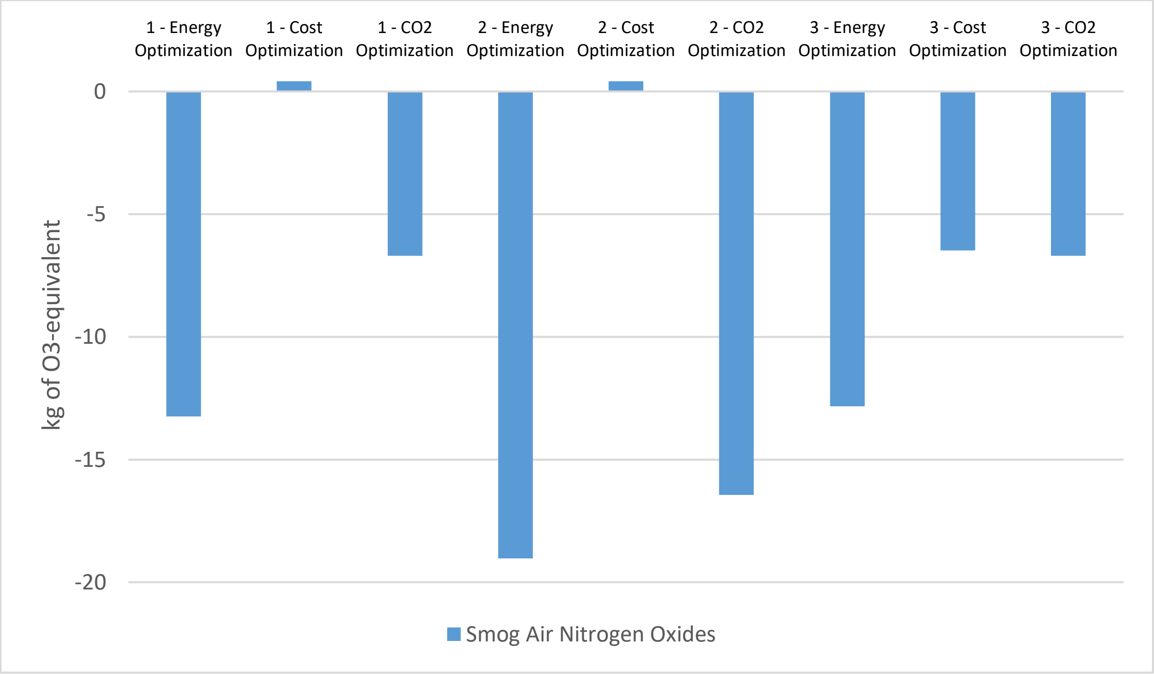

Figure 20: Smog Formation Potential per 1 Ton MSW

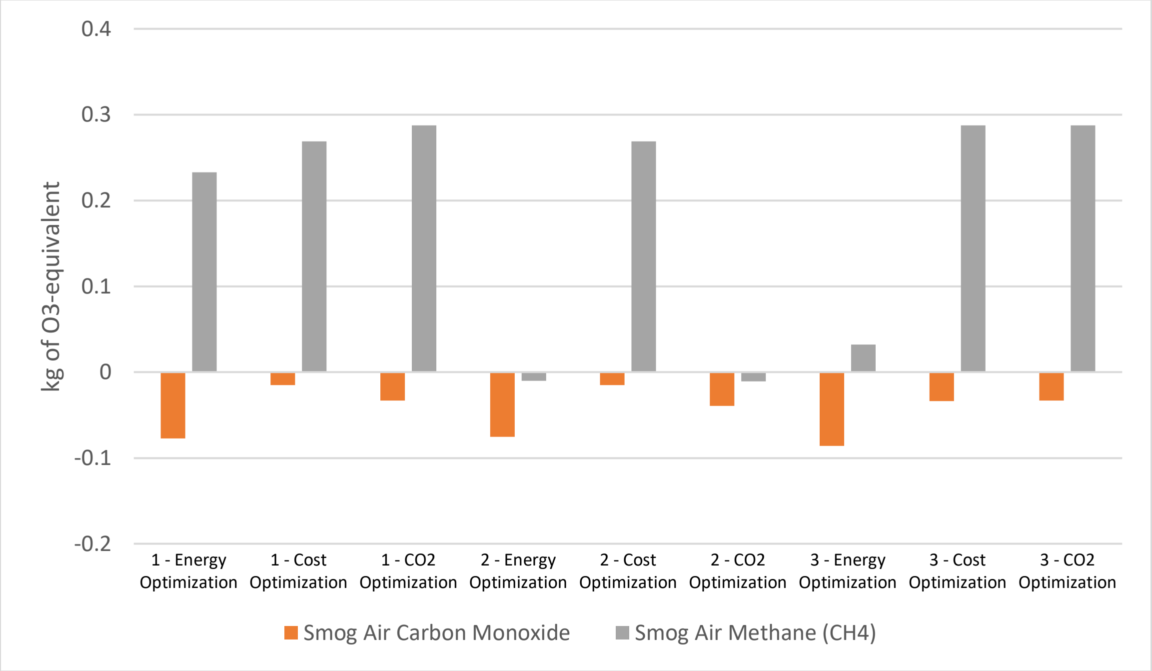

Figure 21: Smog Formation Potential per 1 Ton MSW

Human Health Cancer

Human health cancer results are presented in Figure 22 and Figure 23. This impact calculates lead (air), cadmium, arsenic, mercury (water), and lead (water). Arsenic had the highest expected impact for all Scenarios except Scenario 2 when optimized for energy and CO_2. Results for Scenario 2 optimized for energy and CO_2 show avoidance of all pollutants, especially in the case of arsenic.

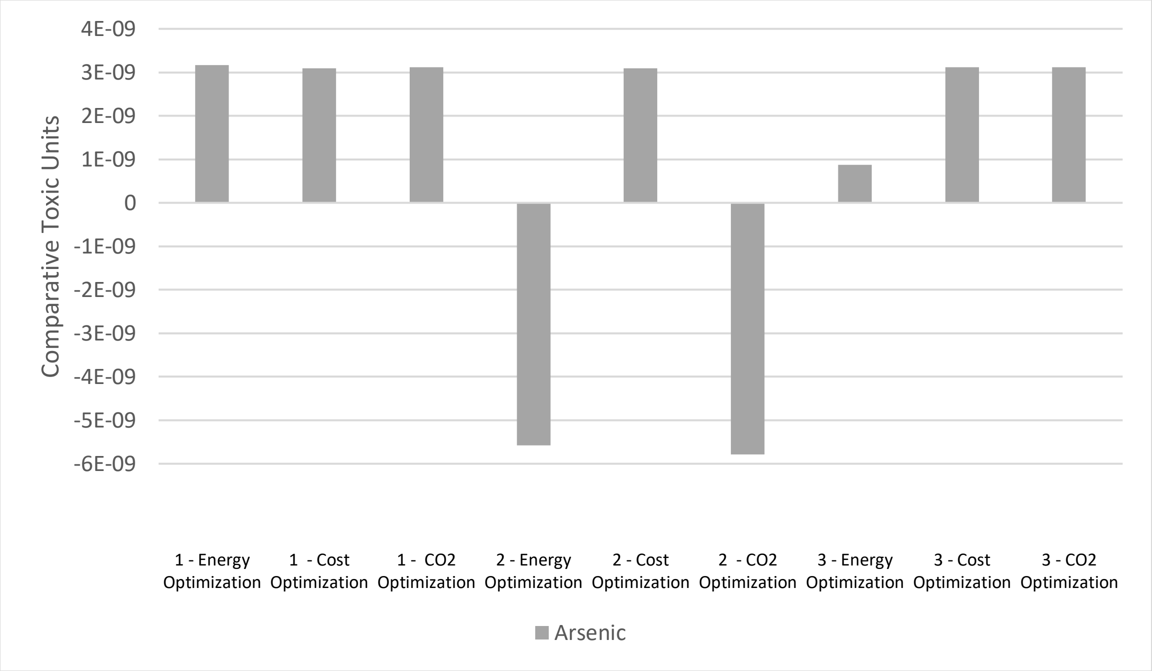

Figure 22: Human Health - Cancer per 1 Ton MSW for Arsenic

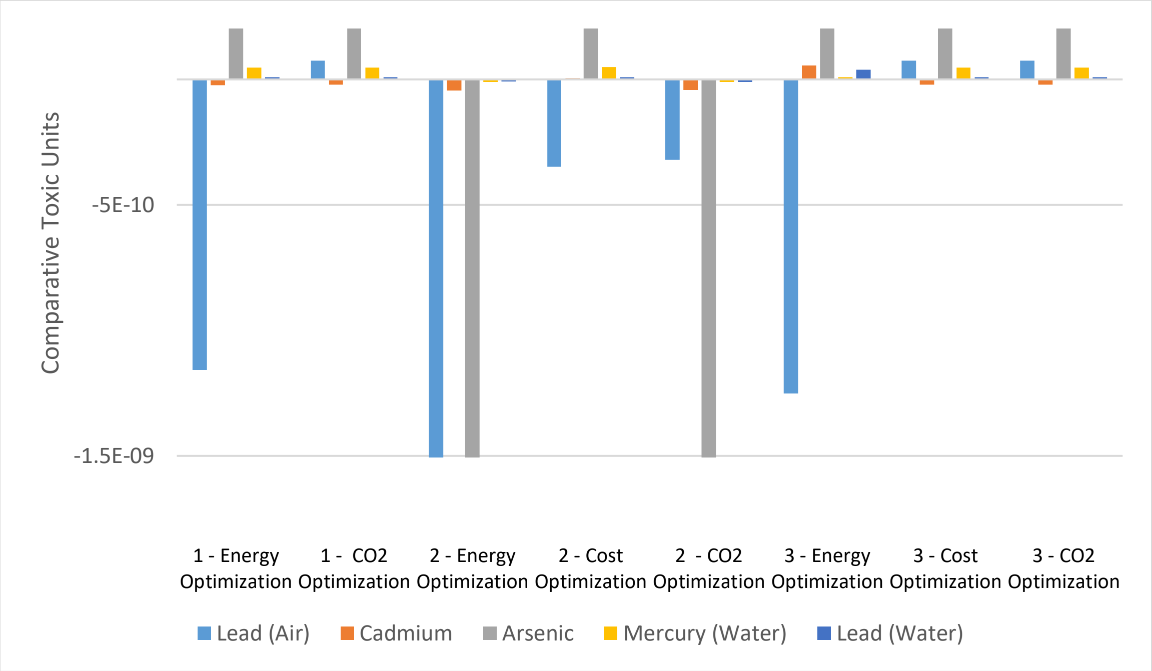

Figure 23: Human Health - Cancer per 1 Ton MSW for Lead, Cadmium, Mercury, and Lead

Human Health-Non-Cancer

The indicators for non-cancer human health impacts included evaluation of the release of lead (air), copper, cadmium, arsenic, mercury (water), chromium, lead (water), and zinc. The results are presented in Figure 24 and Figure 25. Scenario 2 optimized for energy and CO_2 shows avoidance of all human health – noncancer constituents. It is unlikely that complete avoidance of these constituents will occur. Inorganic materials are not destroyed in the process of using these end of life MSW systems. But there is the potential to have the inorganics change to a less harmful and potential no reactive state.

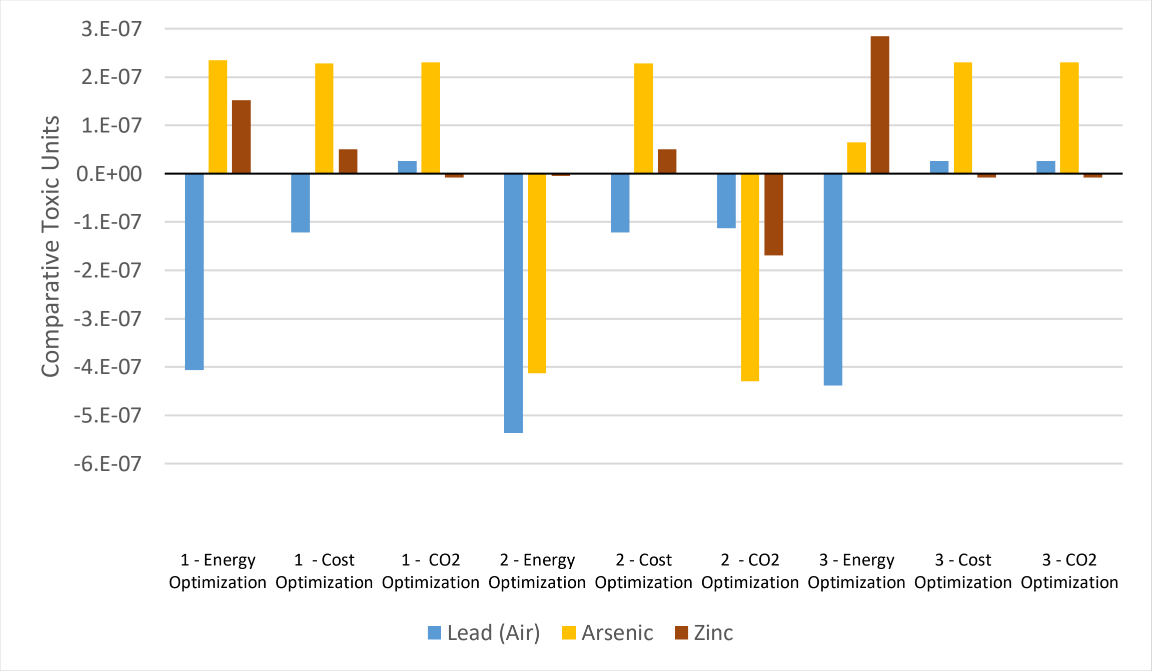

Figure 24: Human Health - Non-Cancer per 1 Ton MSW Lead, Arsenic, and Zinc

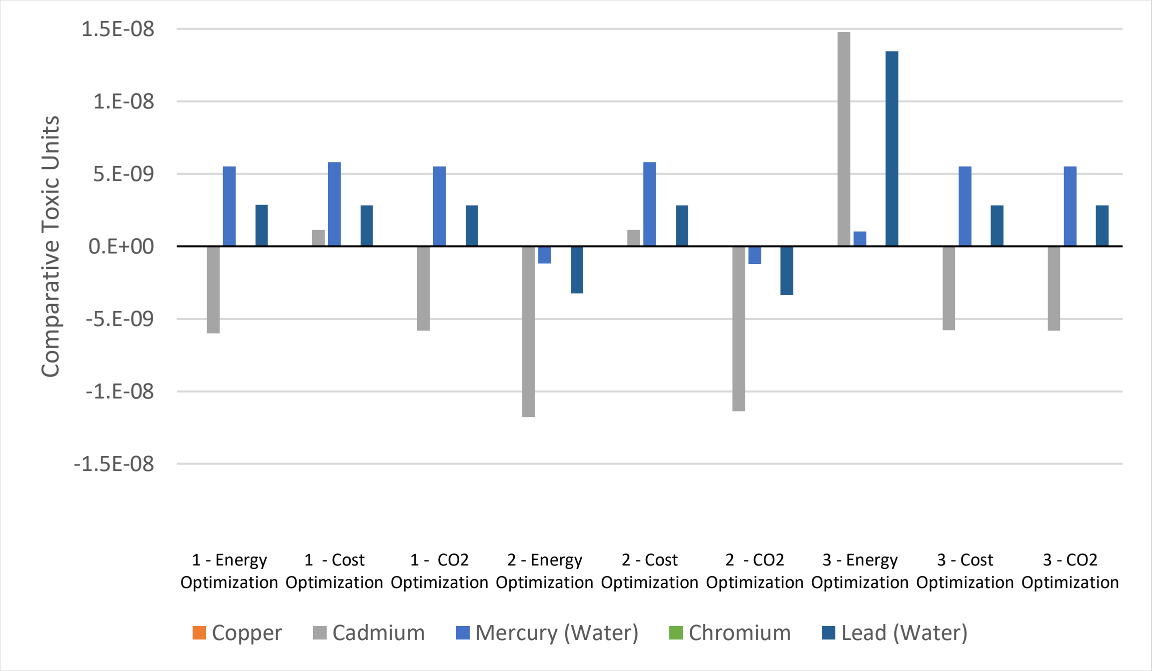

Figure 25: Human Health - Non-Cancer per 1 Ton MSW for Copper, Cadmium. Mercury, Chromium, and Lead

Human Health – Criteria Air Point Source

The indicator for human health -criteria air point sources are evaluated for the release NOx, SOx, and PM10. The results are presented in Figure 26 and Figure 27. All scenarios show an expected avoidance of the indicator pollutants. Scenario 2 optimized for energy and CO_2 have the greatest avoidance.

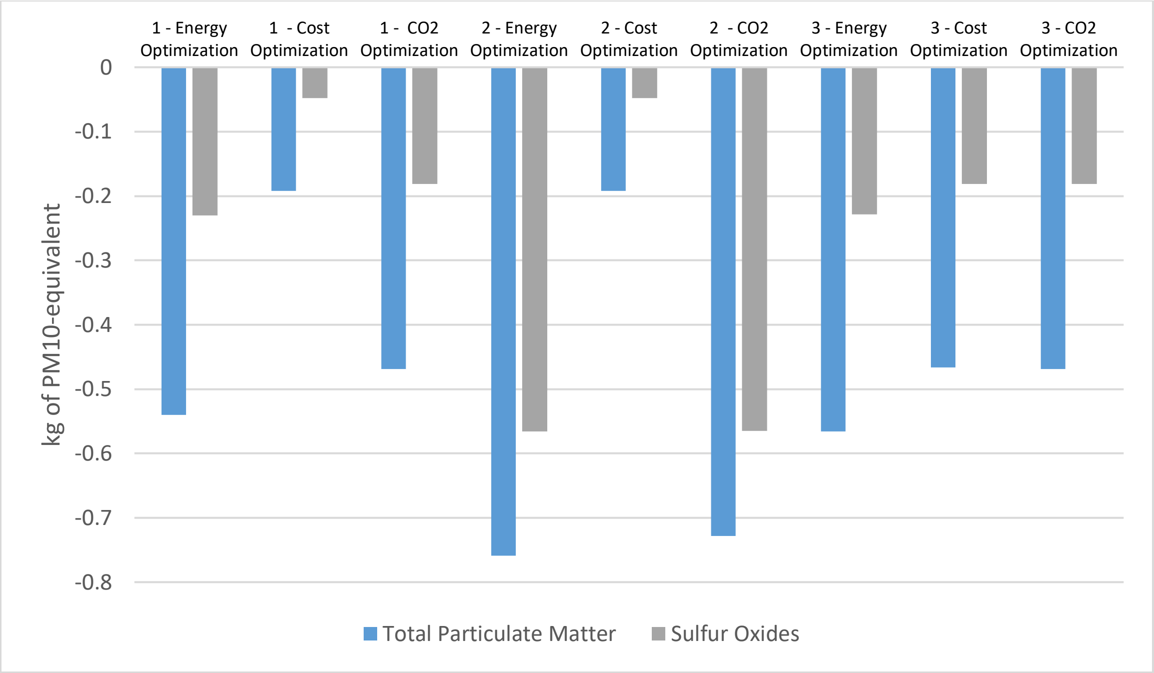

Figure 26: Human Health - Criteria Air-Point Source per 1 Ton MSW for Total Particulate Matter and Sulfur Oxides

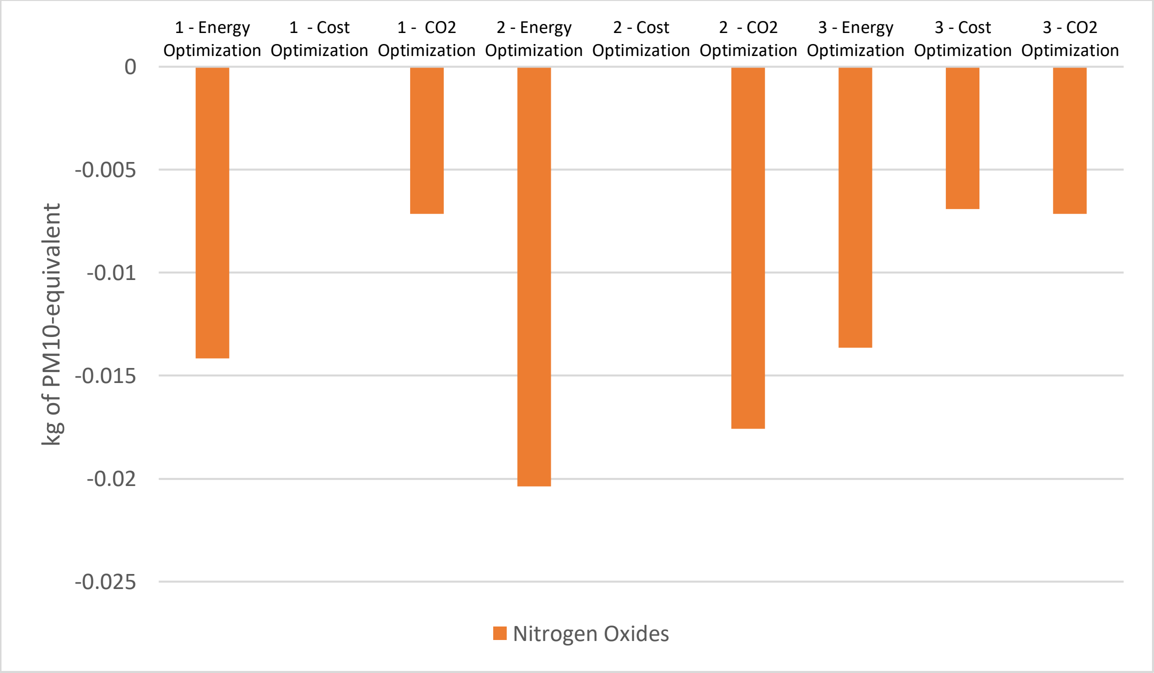

Figure 27: Human Health - Criteria Air-Point Source per 1 Ton MSW for Nitrogen Oxides

Ecotoxicity

Ecotoxicity is the impact that constituents have on the ecological systems through biological, chemical, or physical stressors. Pollutants with the potential to impact ecological systems include lead (air), ammonia (air), iron, copper, cadmium, arsenic, mercury (water), selenium, chromium, lead (water), and zinc. Results for all scenarios are presented in Figure 28 and Figure 29. Scenario 2 optimized for energy, and CO_2 has avoidance for all ecotoxicity indicators.

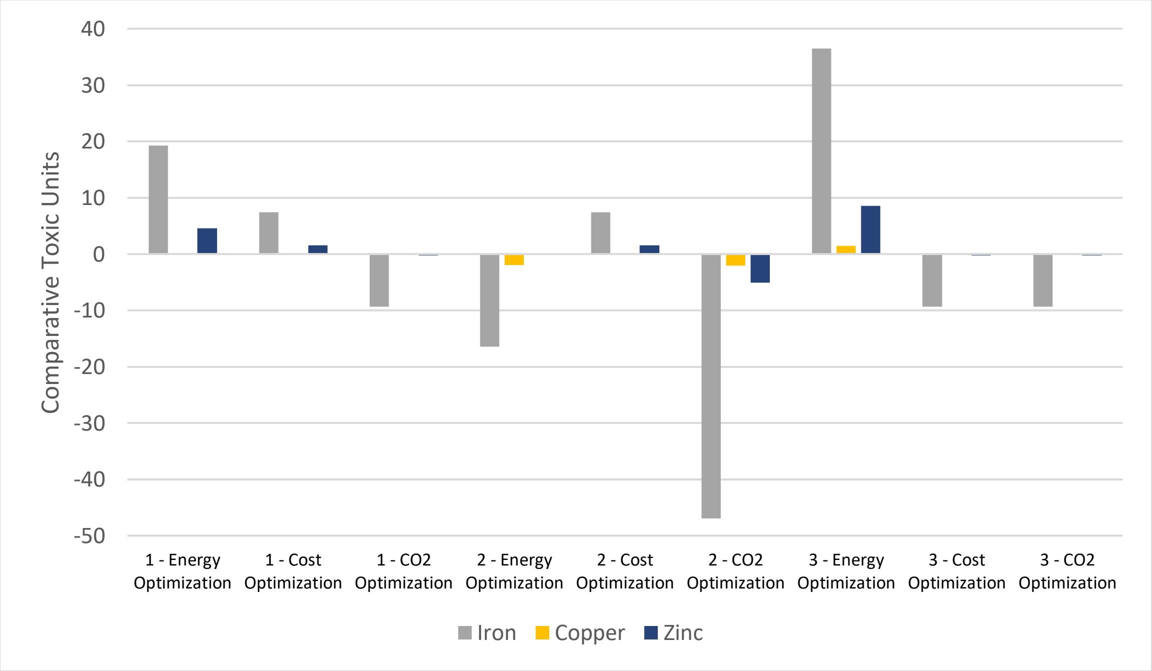

Figure 28: Ecotoxicity Potential per 1 Ton MSW for Iron, Copper, and Zinc

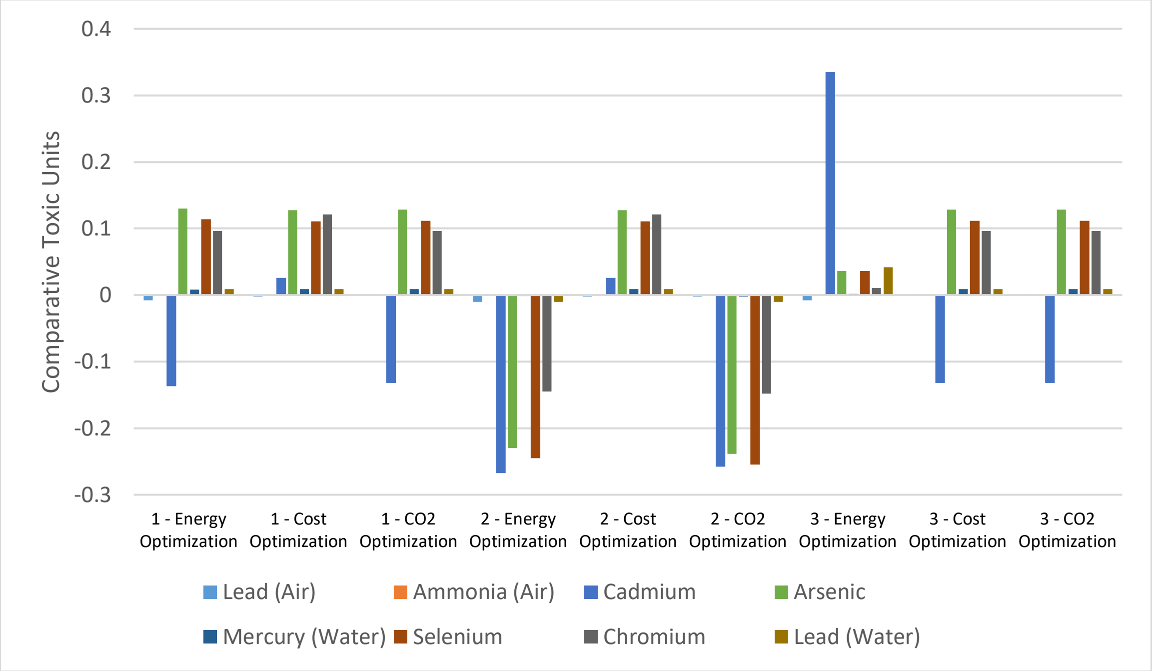

Figure 29: Ecotoxicity Potential per 1 Ton MSW for Remaining Constituents

Discussion and Conclusion

Least and Greatest Case Scenarios

A summary of the emission results from the LCA is shown in Table 8. In most cases, Scenario 2 yielded the lowest environmental impact when optimized for energy and CO_2. Optimizing for cost typically yielded a greater impact. Cells highlighted in green represent an avoidance of emissions, which has a positive effect on the environment.

Table 8: Life Cycle Assessment Emission Results

		Least Impact	Greatest Impact
Global Warming	CO_2	Scenario 2 Optimized for CO2	Scenario 1 Optimized for Cost/Scenario 2 Optimized for Cost
Acidification	Ammonia	Scenario 2 Optimized for CO_2	Scenario 1 and 2 Optimized for Cost
	Sulfur Oxides	Scenario 2 Optimized for Energy and CO_2	Scenario 1 and 2 Optimized for Cost
Eutrophication Air/Water	Ammonia	Scenario 2 Optimized for Energy and CO_2	All of Scenario 1, Scenario 2 Optimized for Cost, Scenario 3 Optimized for Cost and CO_2
	Water COD	CO_2 Scenario 2 Optimized for CO_2	Scenario 1 for CO_2 and Scenario 3 for Cost and CO_2
	Water Phosphate	Scenario 2 Optimized for Energy and CO_2	Scenario 3 Optimized for Energy
	Nitrogen Oxides	Scenario 2 Optimized for Energy	Scenarios 1 and 2 Optimized for Cost
Ecotoxicity Air	Ammonia	Scenarios 1, 2, 3 Optimized for Energy	Scenario 2 Optimized for CO_2
	Lead	Scenario 2 Optimized for Energy	Scenario 1 Optimized for CO_2 Scenario 3 Optimized for Cost and CO_2
Ecotoxicity water		Scenario 2 Optimized for CO_2	Scenario 3 Optimized for Energy
Smog air	Nitrogen Oxides	Scenario 2 Optimized for Energy	Scenarios 1 and 2 Optimized for Cost
	Methane	Scenario 2 Optimized for Energy and CO_2	Scenarios 1 and 3 Optimized for CO_2 and Scenario 3 for Cost
Human Health Cancer		🟩	🟨
Human Health Noncancer Air Point Source	Total Particulate Matter	Scenario 2 Optimized for Energy	Scenario 1 and Scenario 2 Optimized for Cost
Reference:	Emission (greater than zero)	🟩	
	Avoidance (less than zero)	🟨	

Limitations

Several limitations exist when using MSW-DST for LCA evaluation. First, the software automatically optimizes operational flows during optimization for cost, energy, and CO_2. This means that there is an omission of certain processes to yield the best potential emission results. It may not be possible for a community to disregard these processes, and therefore the results may not be representative of the system. Therefore, the current MSW system for Metro Nashville is optimized that does not reflect true operational parameters. For example, comingled recycling and yard waste pick are omitted from all scenarios, yet these are a part of Metro Nashville's zero waste plan. When optimized for cost, Scenarios 1 and 2 provided the lowest cost. In both optimized cases, all materials were sent to an MSW landfill, even though Scenario 2 considers waste to energy for the end of life management technology. When optimized for energy and environmental impact, Scenario 2 yields the lowest energy and environmental impact.

The LCA was performed based on preliminary information for end of life MSW systems for Metro Nashville. Default values were utilized, which may not be representative of operations in Metro Nashville. Therefore, additional data collection is necessary as planning continues to better characterize the cost and environmental impact.

Streamlined Life Cycle Assessment

As discussed in Chapter II, SLCA does not provide a rigorous quantitative environmental impact evaluation. Instead, it is a useful tool to identify environmental 'hot spots' and highlight key opportunities for creating environmental improvements. SLCA follows the guidelines established in ISO 14040 but simplifies the environmental system boundary, limits the data collected and analyzed, and simplifies the evaluation of environmental impacts. Based on the review of SLCA methodologies, the Environmentally Responsible Product Assessment (ERPA) method developed by Thomas Graedel is utilized for use in the development of the decision framework, as discussed below.

Application of Environmentally Responsible Product Assessment

ERPA is considered in place of the Full LCA because it allows the user to reduce the number of life cycle stages and respective environmental impacts. In the preliminary planning stage, there is often little information on the major components of environmental systems evaluation, such as energy consumption needs, location, system infrastructure, and emissions of the evaluated system, without the use of LCA modeling software or databases. Instead, experts and practitioners provide input based on their technical understandings of the evaluated environmental system to assess and rank the environmental impact of the life cycle stages. Non-experts are not utilized for this type of evaluation, because they lack the technical knowledge and are likely to express opinions rather than technical knowhow in their evaluations.

Graedel's ERPA methodology was initially developed for manufacturing evaluation and utilized the following steps:

Stage 1: Pre-manufacturing, which involves the suppliers providing (generally) virgin resources and producing materials and components.

Stage 2: Manufacturing operation.

Stage 3: Product delivery (directly under corporate control).

Stage 4: Customer use stage.

Stage 5: The refurbishment, recycling, or disposal of the item once it is deemed to no longer be needed.

ERPA provides a direct comparison between related products, to be usable and consistent across different assessment teams, to encompass all major stages of product life cycles and all relevant environmental stressors, and to be simple enough to allow for relatively quick and inexpensive assessment (Graedel, 1998).

The matrix attempts to approximate the results of the more formal LCA inventory analysis (LCIA) and impact analysis stages of LCA. Because this approach is not completely quantitative, the results are not strictly a measure of environmental performance, but rather estimate the potential for improvement in environmental performance. The ERPA process utilizes a 5x5 matrix to assess five major life cycle stages within an established boundary with respect to five environmental impacts. Life cycle stages can include product design, manufacturing, packaging, in-use environment, and likely disposal scenarios. The impact is evaluated by assigning an integer from 0 to 4, where 0 represents the highest impact and the most negative evaluation, and 4 represents the lowest impact and the least negative evaluation (Graedel, 1998). The process developed is purposely qualitative and utilitarian but does provide a numerical endpoint against which to measure improvement. The assessor is guided by their expertise and appropriate guidance documents, which provide information for each life cycle stage as compared with each environmental stressor. Besides manufacturing, Graedel considered additional uses for ERPA, as shown in

Table 9.

Table 9: Life Cycle Stages and Environmental Stressors Identified by Graedel

	Life Stages	Environmental Stressors
Process (generic)	Premanufacture Product Manufacture Product Delivery Product Use Refurbishment, Recycling, Disposal	Materials Choice Energy Use Solid Residues Liquid Residues Gaseous Residues
Process	Resource Provisioning Process Implementation Primary Process Operation Complementary Process Operation Refurbishment, Recycling, Disposal	Materials Choice Energy Use Solid Residues Liquids Gaseous
Facility (generic)	Site Selection, Development, Infrastructure Principle Business Activity -Products Principle Business Activity -Processes Facility Operations Refurbishment, Transfer, Closure	Biodiversity, Materials Energy Use Solids Residues Liquid Residues Gaseous Residues
Facility	Site and Service Development Service Provisioning Facility Operations Providing the Service Site and Service Closure	Biodiversity, Materials Energy Use Solids Residues Liquid Residues Gaseous Residues
Societal Infrastructure	Site Development Materials and Product Delivery Infrastructure Manufacture Infrastructure Use Refurbishment, Recycling, Disposal	Ecological Impacts Energy Use Solids Residues Liquid Residues Gaseous Residues

(Graedel, 1998)

Although the assignment of integer ratings seems subjective, it was found that the evaluation of various systems by a group of experts, in which consistency guidance is provided, returned similar results in the environmental ranking (Graedel, 1998).

Limitations are observed with the use of ERPA. For example, in the evaluation to determine electric cars' ability to provide a significant reduction in fossil fuels and CO_2 emissions depending on the types of electricity used, ERPA was unable to provide a conclusion, since not enough information was provided on the production of electricity prior to use was not included.

Also, since experts are used to provide the ranking, there is a level of arbitrariness between assessors. Concerns may exist that assessors did not have adequate knowledge of all aspects of a product's life cycle and, therefore, may have had difficulty evaluating processes downstream (Hochschorner & Finnveden, 2003).

When used to evaluate cell phone life cycle for eco-design considerations, considering pre-manufacturing, manufacturing, use, and end of life of a cellular phone, ERPA illustrated areas of potential environmental improvements, even though only semi-quantitative information was utilized. Environmental performance scores were subjective and finding data to support the score estimation was difficult. The difficulty could arise if a product system is new, and limited information is available for evaluation. But, overall, the study found that ERPA was useful in identifying areas of potential improvement (Lee et al., 2003).

Streamlined Life Cycle Assessment for End of Life Municipal Solid Waste Management Systems

To test the SLCA's ability to be utilized in place of a Full LCA to create boundaries for an environmental system and to evaluate impacts at various life cycle stages, end of life MSW management systems for Metro Nashville were evaluated using ERPA. The system boundary and general inputs utilized in the Full LCA are shown in Figure 30.

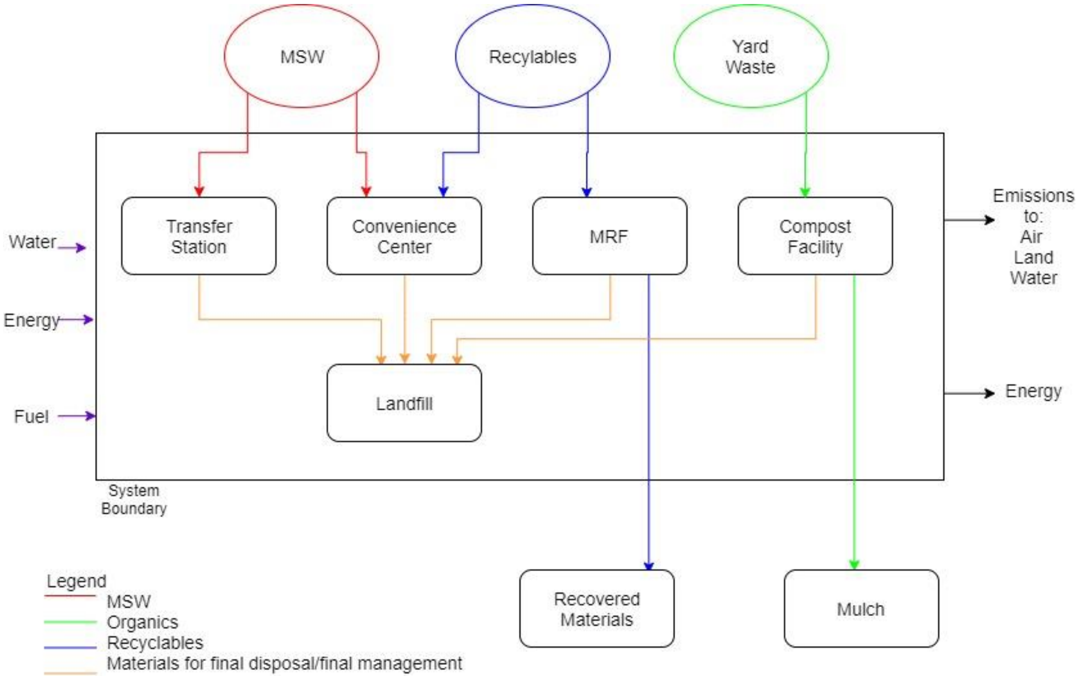

Figure 30: Full Life Cycle Assessment Boundary for Evaluation of End of Life Municipal Solid Waste Management System

For the SLCA, only residential MSW was considered, since it amounts to the greatest amount of MSW that Metro Nashville manages. Bulk yard waste and recyclables were excluded from this evaluation since these systems are managed separately from MSW.

Municipal Solid Waste End of Life Scenarios

Three MSW management scenarios (from curbside pick up to end of life management) are evaluated for environmental and energy impacts. As with the Full LCA, the scenarios are hypothetical cases based on current Metro Nashville MSW operations and include:

- Scenario 1: Landfilling
- Scenario 2: Waste to energy facility with associated landfill and
- Scenario 3: MSW composting with associated landfill

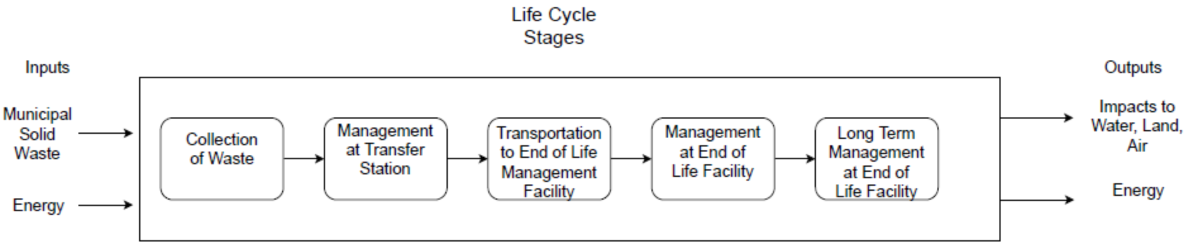

Figure 31: Streamlined Life Cycle Assessment Boundary for Municipal Solid Waste End of Life Municipal Solid Waste Management System

As shown above, the SLCA scenarios include five life cycle stages, with the first three being the same for all of the scenarios. The life cycle stages include:

1. Collection of Waste: Collection of MSW from residential locations utilizing standard side -and rear collection trucks. Once trucks are full, they transport waste to the transfer station within the metropolitan area.
2. Management at Transfer Station: Once at the transfer station, collection trucks dump MSW on the tipping floor at the transfer station. MSW is then transferred into trailers for transport to end of life management facilities. The facility is completely enclosed, and any leachate produced is pumped to a municipal wastewater treatment facility for additional treatment.
3. Transportation to End of Life Management Facility: Upon loading the MSW into trailers, it is transported by truck to the end of life management facility. It is assumed that the end of life management facility is located no more than 30 miles from the transfer station.
4. Management at End of Life Facility: Once the MSW has arrived at the end of life facility, it is processed and managed. For Scenario 1, MSW is dumped from trailers into the landfill, where it is compacted and covered per regulations. For Scenario 2, MSW is processed and incinerated to produce steam and electricity. Residual materials are

disposed of at an onsite permitted landfill. For Scenario 3, MSW is processed, separated, and composted. Residual materials are disposed at an onsite permitted landfill

5. Long Term Management at End of Life Facility: For Scenarios 1, 2, and 3, long term management includes the collection of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing structures such as collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post-closure period.

Environmental Impacts

The five environmental impact categories evaluated include (1) solid waste managed, (2) energy, (3) air emissions, (4) water emissions, and (5) land impacts. Each impact category relates to the impact, potentially negative or positive, expected to be encountered at each life cycle stage. The impacts are defined as:

1. Solid Waste Managed: the impact relates to the amounts of MSW managed at each life cycle stage. This considers how much waste is disposed of at each life cycle stage. Diverted materials such as recyclable or organic tree waste are not considered in this study are considered separate streams from the MSW.
2. Energy: the impact relates to the amount of energy needed for each life cycle stage, as well as considers any energy production, energy use minimization, or any energy efficiency methods used.
3. Air emissions: the impact relates air emissions for each life cycle stage, including effects to air quality based on the emissions produced or avoided.
4. Water emissions: the impact relates to water emission for each life cycle stage, including effects on water quality (surface and groundwater) based on the emissions produced or avoided.

5. Land Impacts: the impact related to land impacts for each life cycle stage, including short term and long-term land use.

Municipal Solid Waste End of Life Scenarios

The SLCA evaluation process involves considering the environmental impact at each life cycle stage. The evaluator assigns a value of impact from zero to four for each life cycle stage and inputted into the matrix shown in Table 10. The zero is given to an impact seen as having a significant impact on an environmental stressor (worst case). If a life cycle stage has minimal or no environmental impact, then a four is assigned (best case). Values between one to three are provided for impacts between the best and worst cases. A rubric is used to provide framing and guidance for evaluators to assign values to impacts for each life cycle stage. A copy of the rubric is provided in Appendix A The imputed values are summed to calculate a cumulative environmental impact score for each scenario.

Table 10: Streamlined Life Cycle Assessment Matrix

	Environmental Impact				
Life Cycle Stages	Solid Waste Managed	Energy	Air Emissions	Water Emissions	Land Impacts
Collection of Waste					
Management at Transfer Station					
Transportation to End of Life Management Facility					
Management at End of Life Facility					
Long Term Management at End of Life Facility					

The steps to complete the matrix are as follows:

1. Review the description of the system being evaluated.
2. Review the rubric for all elements of the matrix in Table 11.
3. Assign a value of zero to four for each life cycle stage and impact.
4. Iterate Steps one to three as necessary until all life cycle stages have an impact value.

Solid waste experts complete the matrix because of their familiarity and operational knowledge with MSW systems, their operations, and their impacts.

Elicitation Documents

A two-page SLCA process summary was prepared for the experts to review before the completion of the matrix, as shown in Table 11. The experts were also given the rubric, which frames each life cycle stage and environmental impact. The rubric presents a series of questions for the experts to consider while completing the matrix. Table 11 shows an example of the guiding questions.

Table 11: Example of Question for Evaluation of SLCA Evaluation

Matrix Element 1,1: Solid Waste Managed for Collection of Waste	Life Stage: Collection of Waste Environmental Impact: Solid Waste Managed			
Matrix Rating	0	1-3	4	Rating
	Is all waste disposed of by residential customers collected by the collection vehicles for transport to the transfer station?	If waste is collected, what percentage produced by residential customers is diverted for recycling, reuse, composting, etc. (waste diversion)?	Is all waste diverted to recycling, reuse, composting, etc. facility and not collected by collection vehicle for transport to the transfer station?	

Elicitation of Streamlined Life Cycle Assessment

The expert elicitation tested the SLCA's ability to frame the environmental system to be evaluated and allow for a simplified method to assess environmental impacts. The Vanderbilt Institutional Review Board reviewed the elicitation process and methodologies. The experts completed the SLCA process using Google Forms. The results are presented Appendix B. The compiled results provide a ranking of the environmental impacts for each life cycle stage, where a higher represents less impact.

Selection of Experts

The experts to complete the SLCA were selected based on their experience in various aspects of managing MSW. The elicitation experts self-identified their associated MSW sector. The five participants included two Solid Waste Authority/County Solid Waste Director/and or Operator (Experts 1 and 2), two Regulators (Experts 4 and 5), and one Corporate Landfill Manager/Operator (Expert 3).

Elicitation of Experts

The elicitation results for the three scenarios are presented in the following sections.

Results for Scenario 1: Landfilling

The results of the experts' evaluation of the SLCA for Scenario 1 are in Table 12 and

Table 13. The total environmental impact scores ranged from 29 to 72, where the average score was 49.6. When the scores were average, solid waste managed has the most significant environmental impact, and land impacts the least environmental impact. For life cycle stages,

end of life management at the landfill had the most significant amount of environmental impact, and management at transfer stations had the least environmental impact.

Table 12: Scenario 1 SLCA Results for Environmental Impacts

Scenario 1	Solid waste Managed	Energy	Air Emissions	Water Emissions	Land Impacts	Sum
Expert 1	14	9	9	9	15	56
Expert 2	18	10	12	15	17	72
Expert 3	8	8	10	11	12	49
Expert 4	3	13	8	8	10	42
Expert 5	1	6	8	8	6	29
Average	8.8	9.2	9.4	10.2	12	49.6

Table 13: Scenario 1 SLCA Results for Life Cycle Stages

Scenario 1	Collection of Waste	Management at Transfer Station	Transportation to End of Life Management Facility	End of Life Management	Long Term Management at End of Life	Sum
Expert 1	10	10	13	11	12	56
Expert 2	11	16	14	16	15	72
Expert 3	13	10	13	4	9	49
Expert 4	11	10	6	6	9	42
Expert 5	7	9	2	2	9	29
Average	10.4	11	9.6	7.8	10.8	49.6

Results for Scenario 2: Waste to Energy

The results of the experts' evaluation for Scenario 2 are in Table 14 and

Table 15. The results showed that the environmental impact scores ranged from 32 to 75. The average score was 51.8. When averaged, energy has the most significant environmental impact, while land impacts had the least environmental impacts. For life cycle stages, end of life

management at the waste to energy facility had the most significant amount of environmental impact, and long-term management had the least environmental impact.

Table 14: Scenario 2 SLCA Results for Environmental Impacts

Scenario 2	Solid waste Managed	Energy	Air Emissions	Water Emissions	Land Impacts	Sum
Expert 1	14	12	11	11	16	64
Expert 2	18	12	11	16	18	75
Expert 3	8	5	10	12	15	50
Expert 4	4	9	7	7	11	38
Expert 5	4	2	8	10	8	32
Average	9.6	8	9.4	11.2	13.6	51.8

Table 15: Scenario 2 SLCA Results for Life Cycle Stages

Scenario 2	Collection of Waste	Management at Transfer Station	Transportation to End of Life Management Facility	End of Life Management	Long Term Management at End of Life	Sum
Expert 1	10	10	13	15	16	64
Expert 2	11	16	14	17	17	75
Expert 3	13	10	13	6	8	50
Expert 4	11	10	6	4	7	38
Expert 5	7	9	2	6	8	32
Average	10.4	11	9.6	9.6	11.2	51.8

Results for Scenario 3: Municipal Solid Waste Composting

The results of the experts' evaluation of the SLCA for Scenario 3 are in Table 16 and

Table 17. The environmental impact scores ranged from 35 to 70, with an average score of 51.4. Solid waste managed and energy have the most significant environmental impact, while land impacts had the least environmental impacts. For life cycle stages, the MSW composting

facility had the greatest amount of environmental impact had the most significant, while long term management had the least environmental impact.

Table 16: Scenario 3 SLCA Results for Environmental Impacts

Scenario 3	Solid waste Managed	Energy	Air Emissions	Water Emissions	Land Impacts	Sum
Expert 1	12	8	9	11	15	55
Expert 2	18	11	11	14	16	70
Expert 3	9	8	11	11	14	53
Expert 4	3	11	9	9	12	44
Expert 5	1	6	12	9	7	35
Average	8.6	8.8	10.4	10.8	12.8	51.4

Table 17: Scenario 3 SLCA Results for Life Cycle Stages

Scenario 3	Collection of Waste	Management at Transfer Station	Transportation to End of Life Management Facility	End of Life Management	Long Term Management at End of Life	Sum
Expert 1	10	10	13	10	12	55
Expert 2	10	16	14	15	15	70
Expert 3	13	10	13	8	9	53
Expert 4	11	10	6	4	13	44
Expert 5	7	9	2	4	13	35
Average	10.2	11	9.6	8.2	12.4	51.4

Combined Results

The combined results for each scenario are presented in Table 18 and Table 19. Experts 1 and 2 ranked the environmental impacts of the three scenarios in the same way, with Scenario 3 seen as having the greatest environmental impact, while Scenario 2 had the least amount of environmental impact. Experts 3, 4, and 5 selected Scenario 3 as the scenario with the least environmental impact. Additionally, the ranked Scenario 3 as the scenario with the least amount of environmental impact.

Table 18: Summary of SLCA Results

	Scenario 1	Scenario 2	Scenario 3
Expert 1	56	64	55
Expert 2	72	75	70
Expert 3	49	50	53
Expert 4	42	38	44
Expert 5	29	32	35

Note: Highlighted cells indicate the least impact

There is a wide difference between expert inputs. Though Scenario 1 was rank as having the greatest environmental impact, the impact scores ranged from 29 to 72. For Scenario 2, Experts 4 and 5, who are both regulators, had a similar order of magnitude. Experts 1 and 2 selected Scenario 2 as having the least impact, yet the vales for Expert 2 are similar in magnitude as Scenarios 1 and 3. There is not a clear consensus that can be concluded from this evaluation. To evaluate group rankings, experts' results were compiled using standard arithmetic and geometric mean. Using the average, Scenario 2 and 3 were 51.8 and 51.4, respectively. For geometric mean, Scenario 3 was the scenario with the least amount of impact. The ranking of scenarios was similar using arithmetic average and geometric mean.

Table 19: Average Scores for SLCA Results

	Arithmetic Average	Geometric Mean
Scenario 1	49.6	47.5
Scenario 2	51.8	49.3
Scenario 3	51.4	50.1

Comparison of LCA and SLCA

The results of the LCA and SLCA were compared to determine if SLCA to be used in place of LCA when preliminary evaluation of environmental systems. Full LCA considers as many more inputs and processes of a system as reasonable and is useful when a system fully characterized and understood. It provides an accurate evaluation of environmental impact. Software packages and databases are required for the calculation of environmental impacts. Full LCA is quantitative; therefore, it can be tailored to a specific system to estimated emissions. SLCA allows for simplification of the system boundary and inputs, considering only five environmental impacts and five life cycle stages. The SLCA reduces the number of steps to allow for a preliminary evaluation of environmental impacts. Additionally, the process can be completed using expert input and basic spreadsheets. The cost is significantly less and, the process easier to deploy.

Full LCA and SLCA were compared in the evaluation of end of life MSW management for Metro Nashville. Both methods were able to develop system boundaries for assessment and determined Scenario 1 as having the most significant environmental impact. But experts' evaluation of the scenarios in SLCA disagreed on which scenario had the least amount of environmental impact. The human aspect of SLCA can potentially cause a disagreement in the outcome, since there may be some subjectivity in the responses. Full LCA using MSW-DST optimizes the scenarios for cost, energy, and CO_2, SLCA looks at the standard system operations. The SLCA results do not provide an adequate means to compare environmental impacts with the LCA.

Reasons there are differences include, but are not limited to:

- The LCA evaluated more system steps than the SLCA, which may affect environmental impact values.

- A limited number of experts were available in the elicitation. In the future, more experts can provide additional evaluation for creating a group average.
- Additional training is recommended for experts. Experts received a simple outline of the elicitation process and the rubric to guide them through the impact evaluations. Further training by either face to face or via recorded presentation will help in aligning experts' understood of the process.
- For SLCA, the assessed impacts for air, water, and land were general, since they didn't specify specific constituents of concern. The experts might provide better impact assessment if specific constituents were considered. For example, the SLCA air emissions could be better defined as emissions of methane or carbon dioxide.
- Land impacts were not quantified by the full LCA process. This parameter could not be compared with the Full LCA. Therefore, there was not the ability to analyze if these two assessment methods were similar.

SLCA is useful in aiding in the simplification of system boundaries for environmental impact assessment. In the planning stages, there may be limited knowledge in a waste management system. However, there is an understanding of the basic steps necessary in the system, which can aid in preliminary evaluation and planning. As the system is better defined, the iterative process of LCA can be applied, and the system can be expanded to include additional steps.

CHAPTER IV

Methodological Development of DecisionTogether©

Introduction

Environmental decision-making is difficult and complex, especially in the planning stages of a project. Finding consensus with diverse stakeholders is difficult, and often the outcomes are difficult to interpret, utilize, or implement. This is true when stakeholders attempt to make decisions related to environmental system selection when environmental impacts are overshadowed by other criteria that are perceived to take precedence (e.g., economics, social concerns). Often, economics can dominate other criteria, such as environmental impact and societal concerns (Giddings et al., 2002). Trade-offs exist between the evaluated criteria, and they may not be linearly comparable. A methodological decision framework is needed to aid diverse stakeholders in their evaluation of environmental systems, to identify the criteria of concern, and to select the most preferred alternative.

Decisions are made based on current knowledge and perspective and are used to evaluate future systems and potential alternatives for development. A methodological decision framework is needed to integrate qualitative and quantitative data and allow stakeholders to understand areas of consensus or disagreement, allowing for the development of a path forward. This process does not select the final choice but helps establish an understanding of where the group's preferences lay.

To make environmental development useful and operational to most stakeholders, a convergence of four aspects must occur:

- Science and technology must exist support;

- Policies and regulatory frameworks must be well-formulated;
- Businesses should be actively involved, and
- Public stakeholders must understand and support it by incorporating their voices in the process and being able to understand the results in an interactive manner (Halog & Manik, 2011).

This chapter discusses the development of DecisionTogether©, a generic methodological decision framework that integrates environmental system development with a decision-making process to provide a means to interface with diverse stakeholders. DecisionTogether© integrates Streamlined Life Cycle Assessment (SLCA) and the Multicriteria Decision Analysis (MCDA) method of the Analytical Hierarchy Process (AHP) to evaluate the trade-offs between pertinent criteria to aid diverse stakeholders to determine preferences and consensus for environmental planning. The collected information from Decision Together will inform future planning and policy development.

This chapter discusses the use of SLCA and AHP for decision-making as well as discusses decision-making theories to develop DecisionTogether©. In Chapter V, DecisionTogether© will be applied to the evaluation of the future end of life systems for municipal solid waste (MSW) management systems by stakeholders.

Stakeholder Engagement in Environmental Decision-Making

Group Decision Making

Group decision making (GDM) involved making a single decision jointly by a group of people, where each participant has their own opinions, concerns, or interests towards the existing alternatives. Still, their opinions or perspectives must be somehow combined to present a representative view to lead the group towards the best and ideally most preferred solution. Classical approaches of decision theory provide suitable methods for solving decision problems defined in a certainty and risk environment. These methods are not adequate to manage decision problems defined under the uncertainty of a non-probabilistic nature, where the information about the problem is vague and imprecise (Palomares Carrascosa, 2018).

Decision-making under uncertainty is categorized in two ways:

- **The number of participants:** A single participant or expert decision process is referred to as an *Individual Decision-Making* problem. Multiple participants or expert decision process is known as *Group Decision-Making*.
- **The number of evaluation criteria:** Some problems require assessing each alternative as a "whole" based on one attribute or evaluation criterion. Others require the evaluation of alternatives in terms of multiple, potentially conflicting evaluation criteria, or multi-attribute or multicriteria decision-making problems.

The following elements characterize GDM:

- The existence of a decision problem to solve;
- A finite set of alternatives or possible solutions, greater than two, typically less than seven; and
- A group of individuals or experts, who express their opinions on a set of alternatives and attempt to find a common or collective solution to the problem.

The solution for a GDM problem is obtained through a direct or indirect approach. Direct approaches involve directly obtained the solution from the individual preferences of experts without constructing a social, collective opinion first. Indirect approaches involve when a social opinion or collective preference is determined *a priori* from the aggregation of individual opinions and are used to find the solution for the GDM problem. Both approaches consist of two stages:

1. Aggregation phase: Individual preferential information from experts is combined by using an aggregation operator.
2. Exploration phase: Identifying the best alternative(s) as the solution to the problem, or establishing a ranking of them from the most to the least preferred alternative by the group (Palomares Carrascosa, 2018).

Examples of GDM use include collaboration versus competitiveness among participants and compatible or incompatible proposals involving different environments. The process to determine a GDM problem solution is influenced by different guiding roles:

- Majority Rule: The decision is made in accordance with the opinions of the majority of experts involved. Once adopting the majority opinion, it must be accepted and respected by the minority position in the group. The notion of majority admits two different ideas for its implementation:
- Absolute majority: The majority option adopted by more than fifty percent of the total number of experts.
- Relative or simple majority: When the majority opinion is the one supported by the highest number of participants, even though the sum of the remaining experts supports different opinions could be higher.
- Minority rule: The decision is delegated to a subgroup of individuals. This rule is frequently adopted for situations where a certain level of expertise is required that not all experts participating in the process may have. This process makes it essential for all experts to accept this rule and agree that delegating needs to occur.
- Individual: This situation results from allowing the decision to be made by a single person in the group, potentially the leader.

- Unanimity: Requires that all experts agree with the decision made. Consensus-based approaches are unanimity, although most of them consider a softer interpretation of unanimity (Palomares Carrascosa, 2018).

Consensus building is an important aspect of the decision-making process. Consensus can become the generally accepted opinion of a group of decision-makers. Consensus assumes that a collective decision-making process is followed, after which no expert disagrees with the decision made, although some of them may consider their preferred solution would work better than the selected solution. To achieve consensus, it may be necessary that most or all stakeholders modify or change their initial opinions, bringing them closer to each other and towards a collective opinion seen as satisfactory by the group. It is important to receive buy-in from stakeholders to ensure that they feel their input and opinions were adequately considered during the decision-making process (Palomares Carrascosa, 2018).

In order to facilitate agreement prior to the evaluation of criteria and alternatives, the Consensus Reaching Process (CRP) may be applied. CRP's primary goal is to obtain a desired level of the agreement before applying the alternative selection process. The process is iterative and dynamic and requires coordination by a moderator. The moderator's purpose is to evaluate the level of existing agreement at each discussion round of the CRP, identify the alternative which causes disagreement between participants, and prevent achieving consensus and inform participants about the changes they should consider in their preferences regarding the alternatives identified.

To complete the CRP, each stakeholder must understand that the purpose of the process is to achieve consensus, and they should clarify any possible questions or doubts before initiating their participation. CRP implies that all experts agree to collaborate with each other and other potentially non-technical stakeholders to find a collectively acceptable solution. If necessary, experts should move from their initial positions, in order to bring their preferences closure to the rest of the group (Palomares Carrascosa, 2018).

Elicitation Process

Seven goals are identified for elicitation activities:

1. Identification of organizational context,
2. Identification of boundaries of a system,
3. Identification of features of a system,
4. Detailed investigation of a given feature,
5. Identification of rationales for requirements,
6. Clarification of uncertainty or ambiguities in requirements, and
7. Requirements of conflict resolution.

Requirements for elicitations depend on the requirements of the engineering process, such as the context of the elicitation, as well as imposed constraints on the selected techniques, alternatives, and criteria. Types of characteristics for an elicitation may include communication among stakeholders, cost/schedule constraints, the skill of participants, relationships between stakeholders, and characteristics of the problem being evaluated. The elicitation process and techniques used by stakeholders depend on the amount of time and consideration they wish to use in the elicitation process.

Factors also affecting the elicitation process may include, but are not limited to:

- Number of stakeholders participating
- Skill/experience of stakeholders
- Availability of key stakeholders
- Stakeholder’s ability to express judgments

- Computer skill level of stakeholders
- Degree of project schedule constraints
- Degree of financial constraints
- Degree of the constant flux of stakeholders
- Diversity of stakeholders
- Relationship among stakeholders
- Availability of communications technology
- Availability of reusable requirements
- Availability of information resources
- Degree of manpower constraint on developers

Implementation techniques should be evaluated to determine if they are appropriate for the degree of expertise and involvement of the stakeholders. Also, the elicitation developer needs to be familiar with the software and materials of the elicitation (Ayalew & Masizana, 2009).

Analytical Hierarchy Process for Decision-Making

AHP was selected for use with the decision-making methodology and is executed by the following steps:

1. Define the problem
2. Develop the hierarchy model
3. Construct a pairwise comparison matrix
4. Perform judgments for pairwise comparison
5. Synthesize the pairwise comparisons
6. Perform consistency verification
7. Complete steps 3-6 for all levels of the hierarchy mode
8. Develop overall priority ranking and select the most preferred element from each tier

Step 1: Define the problem

The problem is defined related to the evaluation to occur. The problem definition is used to develop the goal by which all the pairwise comparisons are made in relation.

Step 2: Develop the hierarchy model

The hierarchy of criteria, attributes, and alternatives/options are developed based on the defined problem. The hierarchy consists of as many levels needed to evaluate the problem. A generic AHP hierarchy is shown in Figure 32. The first level represents the objective or overall goal of the decision process. The second level represents the main criteria to help reach the goal. The third level involves defining any sub-criteria or attributes which further define each criterion. The fourth level evaluates the alternatives with respect to the main hierarchy level above.

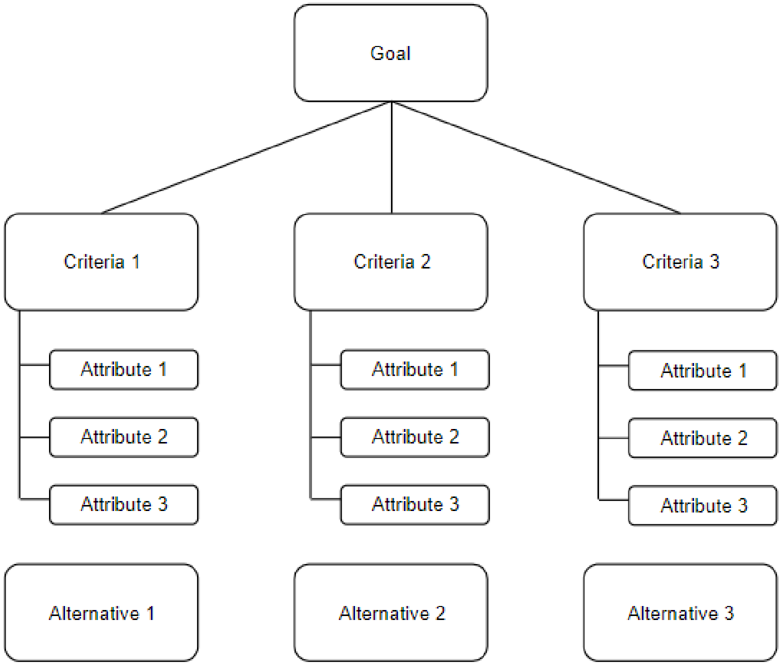

Figure 32: Generic AHP Diagram

Step 3: Construct a pairwise comparison matrix

AHP evaluations are completed through pairwise comparison. The pairwise comparison matrix shows the numerical judgement scale comparison of each tier of the hierarchy (see Table 20 below). The pairwise comparison matrix is sized n by n, where n is the number of compared elements at one tier level. The number of matrices for an AHP evaluation depends on the number of evaluated elements at the different tiers of the AHP hierarchy.

Table 20: Generic Pairwise Comparison Matrix

	Criteria 1	Criteria 2	Criteria 3
Criteria 1			
Criteria 2			
Criteria 3			

Step 4: Perform judgment for pairwise comparison

The pairwise process compares the relative importance of two selected items at a tier level. There are $\frac{n(n-1)}{2}$ judgments required to develop the set of matrices in Step 3. The stakeholder uses the verbal and numerical scale to assign a pairwise value to each comparison, as shown in Table 21. The verbal and numerical judgment scale was developed by Saaty (1980).

Table 21: Verbal and Numerical AHP Judgment Scales

Level of Importance	Definition	Explanation
1	Equal Importance	Two criteria/alternatives contribute equally to the objective
2	Weak or Slight	
3	Moderate Importance	Experience and judgment slightly favor one criterion/alternative over another

4	Moderate Plus	
5	Strong Importance	Experience and judgment strongly favor one criterion/alternative over another
6	Strong Plus	
7	Very Strong or Demonstrated Importance	A criterion/alternative is favored strongly over another; its dominance is demonstrated in practice
8	Very, very strong	
9	Extreme Importance	The evidence favoring one criterion/alternative over another is of the highest possible order of affirmation

(Saaty, 1980)

The judgment is made based on the stakeholders' experiences, knowledge, and perspectives towards the element of preference. A reciprocal value is automatically assigned to each pairwise comparison (Velmurugan, Selvamuthukumar, & Manavalan, 2011). For example in Figure 33, a whole number value is inputted into the matrix for selecting Criteria 1 over Criteria 2, and a reciprocal value would be inputted into the matrix for the evaluation of Criteria 2 over Criteria 1. For example, if a stakeholder selected Criteria 1 over Criteria 2 with a value of 5, the input for Criteria 1 with respect to Criteria 2 would be 5, and the input for Criteria 2 with respect to Criteria 1 would be 1/5.

Figure 33: Pairwise Comparison Example

Step 4: Evaluate the pairwise comparison and calculate

In pairwise comparison, criteria and alternatives are presented and evaluated in pairs for evaluation, weights are derived from each comparison, and an overall rating of the criteria alternatives is constructed. The output presents a priority used for further evaluation or identification of the best alternative. In the AHP evaluation, alternatives are denoted by {A_1, A_2,…, A_n}. The weights of alternatives are denoted as {w_1, w_2, ... w_n}. For example, a matrix representing the weights of a matrix consisting of 3 alternatives (3x3 matrix) is shown in Equation 1.

$$W = [w_i/w_j] = \begin{bmatrix} w_1/w_1 & w_1/w_2 & w_1/w_n \\ w_2/w_1 & w_2/w_2 & w_2/w_n \\ w_n/w_1 & w_n/w_1 & w_n/w_n \end{bmatrix} \; Equation\ 1$$

Comparison matrix A is obtained where a_{ij} shows the preference of alternative A_i obtained by comparison with criteria, where n is the number of compared criteria. Each value for a_{ij} is calculated from w_i/w_j. The pairwise comparison A =[a_{ij}] represents the intensity of a participant's preference for alternatives. For n alternatives, a stakeholder continues to compare the pairs of alternatives for all possible pairs, and a comparison matrix A is obtained, Equation 2.

$$A = [a_{ij}] = \begin{bmatrix} 1 & a_{12} & a_{1n} \\ \frac{1}{a_{12}} & 1 & a_{2n} \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & 1 \end{bmatrix} \; Equation\ 2$$

a_{ij} estimates the ratio w_i/w_j of elements *i* and *j*, which gives the vector of the weights of the alternatives. a_{ij} represents the pairwise comparison of element *i* with respect to element *j*. For the matrix, the row is designated as "i" and the column is designated as "j." All elements in the matrix are positive, $a_{ij}>0$, since each entry in matrix A is positive either as the value or its reciprocal. Once these values are given, a vector of weights associated with A (Alonso & Lamata, 2006).

The matrix results are normalized by summing up the values in each column and then dividing the values in the matrix by the summed value. The normalized values are summed up to yield a vector of priorities, known as the eigenvector. The derived priories are calculated by using the normalized principle to find the maximum eigenvector, λ_{max}. If A is a consistent matrix, that is $a_{ij}a_{jk}=a_{ik}$ for the pairwise comparison; then A is of rank one and the $\lambda_{max} = n$. Results can be aggregated to develop the priority of alternatives against each other using the geometric mean.

Example of Analytical Hierarchy Calculations

For example, when comparing three elements (for example, three criteria), a matrix could be shown in Equation 3:

$$A = \begin{bmatrix} 1 & 1/3 & 5 \\ 3 & 1 & 7 \\ 1/5 & 1/7 & 1 \end{bmatrix} \; Equation\ 3$$

The average normalized column method is used to calculate the vectors of the priorities. The columns of matrix elements are summed, as shown in Equation 4.

$$A = \begin{bmatrix} 1 & 1/3 & 5 \\ 3 & 1 & 7 \\ 1/5 & 1/7 & 1 \end{bmatrix} \; Equation\ 4$$

$$\frac{21}{5} \quad \frac{31}{21} \quad 13$$

The elements of each column are divided by the sum of the column. Then the elements in each resulting row are added. This sum is then divided by the number of elements in the row, which is the process of averaging over the normalized columns, as seen in Equation 5.

$$A = \begin{bmatrix} 5/21 & 7/31 & 5/13 \\ 5/7 & 21/31 & 7/13 \\ 1/21 & 3/31 & 1/13 \end{bmatrix} \; Equation\ 5$$

The priority vector for each element is calculated by summing each row of the matrix and dividing it by the number of elements. For the first row in the matrix above, the priority vector is found, as shown in Equation 6:

$$Priority\ Vecotor\ For\ Row\ 1 = \frac{\frac{5}{21}+\frac{7}{31}+\frac{5}{13}}{3} \quad Equation\ 6$$

$$= 0.283$$

The priority vectors for row two and three are 0.643 and 0.074, respectively. The priority vector is calculated for each row. The maximum eigenvector, λ_{max}, is calculated by multiplying the priority vector by the normalized values calculated, as shown in Equation 7.

$$\lambda_{max} = \left(0.238 * \frac{21}{5}\right) + \left(0.643 * \frac{31}{21}\right) + (0.74 * 13)\ Equation\ 7$$

$$\lambda_{max} = 3.10$$

Consistency

The primary reason AHP is used for decision-making is that stakeholders do not require advanced knowledge of either mathematics or decision analysis methodologies to complete their assessments. Instead, stakeholders are required to understand the problem to complete the decision comparison process. Consistency of the answer process is checked mathematically to ensure the stakeholder is complete the pairwise process consistently. If the consistency check is failed, it is concluded that the stakeholder has been illogical or has made a mistake in the pairwise comparisons process. The recommended course of action is to allow the stakeholder to reevaluate their decisions and revise their comparison are deemed consistent (Karapetrovic & Rosenbloom, 1999).

Saaty (2003) states several ideas about consistency. Completing the entire matrix improves the validity of the judgments made. He considered some inconsistency to be a good thing and that forcing stakeholders to achieve consistency without knowledge of the exact values could lead to undesirable results. If perfect consistency is an elicitation requirement, then the participants are being asked to act mechanical and robotic, unable to represent their real thoughts, feelings, and preferences (Thomas Saaty, 2003). There is the potential that the provided judgments are not true to the stakeholders' views and opinions of the considered elicitation.

Consistency is checked by calculation of the Consistency Index (CI) and the Consistency Ratio (CR). The equation for CI is shown in Equation 8. If the calculated comparison matrix for A is consistent and $\lambda_{max} > n$, there is an indication that there is inconsistency in the evaluation of A (Zeshui & Cuiping, 1999).

Consistency Index is calculated by:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad Equation\ 8$$

Where n = number of activities in the matrix and λ_{max} is the maximum eigenvalue.

The CR is calculated from λ_{max} and a randomization process, which suggests that the eigenvector method is appropriate when CR<0.1 (Zeshui & Cuiping, 1999). CR is calculated by dividing the CI by the random index (RI). The RI values adjust the CI based on the number of elements evaluated as presented in Table 22.

Table 22: Random Index

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

(Saaty, 1980)

Judgments with consistency ratios less than 10 percent (CR<0.1) are considered to be acceptable for use in the evaluation of preference of alternatives (Saaty, 1980). Literature has suggested up to 20 percent is acceptable (Moreno-Jimenez, Aguaron, & Escobar, 2008). Low CR values are difficult to obtain, especially in high order matrices, because of factors such as the limited ability of human thinking and the shortcomings of the one to nine verbal and numerical scale (Zeshui & Cuiping, 1999). Inconsistency can occur during pairwise comparison, where individual judgments can be affected by a lack of rationality and can violate the consistency condition of the matrix. If the CR is greater than 0.1, the matrix can be returned to the participant to reconsider their answers and to improve consistency. This method helps increase consistency but can be tedious and challenging to implement and force the stakeholder to act robotically.

Saaty suggested using CR to determine if an individual is compatible with a group and to determine if the individual departed from the groups' point of view. If consistency is a requirement of the elicitation, then the participants are being asked to act mechanical and robotic, are unable to represent their real thoughts, feelings, and preferences. If consistency is high, a CR greater than 0.1 may be reduced only when the group members can interact and bring down their differences. This situation may not always be possible, as a collection of inputs may occur from people not participating at the same location at the same time by providing their input through questionnaires. In this case, the inputs need to be combined using a group aggregation procedure (Saaty, 1980).

Other means have been developed to improve consistency. One way is to utilize a scale other than Saaty's (1980) linear judgment scale. Other proposed judgment scales include power, root square, geometric, inverse linear, asymptotical, balanced, and logarithmic (Franek & Kresta, 2014). The power and geometric scales extend the values of the matrix elements from 9 to 81 and 256, respectively. Inverse linear and balance scales keep values in the original range but change the weight dispersion. Since these methods calculate CR in different ways, the priorities of one method may not reflect that of another. The root square and logarithmic scales have high consistency sensitivity, while geometric, inverse linear, asymptotical, and balanced scales had low consistency sensitivity. For variance of allocation of priorities' values, power, and geometric were high, and root square, inverse linear, and asymptotic were low (Franek & Kresta, 2014).

Example of Consistency Calculations

For the example shown in Equations 5 and 7, the CI is calculated by:

$$CI = \frac{\lambda_{max}-n}{n-1} = \frac{3.10-3}{2-1}\ Equation\ 9, \text{ where } CI = 0.048$$

The CR is calculated, as shown in Equation 10 below:

$$CR = \frac{CI}{RI} = \frac{0.048}{0.58}\ Equation\ 10, \text{ where } CR = 0.083$$

The RI from Table 22 is *n*=0.58. CR is less than 0.1; therefore, this is a consistent evaluation.

Analytical Hierarchy Process for Group Decision Making

AHP is a method utilized for multicriteria group decision-making (MCGDM) models which involves:

- Individually supplied evaluations of alternatives under several criteria,

- The need to fuse individual assessments into collective assessments, and
- Aggregating collective evaluations across criteria into an overall assessment value for each alternative (Palomares Carrascosa, 2018).

Two important issues in GDM are how to aggregate individual judgments into groups to provide a single representative judgment for the entire group or subgroups and how to construct a group choice from individual choices. The reciprocal property of AHP plays an important role in combining the judgments of several individuals to obtain a single judgment for the group (Thomas Saaty, 2008).

The common objective context that AHP is applied to are:

1. Consensus
2. Voting or compromising
3. Forming the geometric mean of individuals' judgments (Thomas Saaty, 2008)

Consensus

AHP for group consensus building involves the group members meeting together to construct the hierarchy and to make judgments. This approach is attractive because group discussion occurs during the development of the hierarchy, which ensures all relevant information processes by group members, either objective or subjective, are made available to the entire group. Consensus also allows group members to feel that they are "owners" of the decision and encourages them to do their best to ensure a successful implementation. In some decisions, being able to arrive at consensus may be more important than the choice of the alternative, mainly if the alternatives are not drastically different from each other, and the success of the decision depends on subsequent implementation efforts of the stakeholders (Dyer & Forman, 1992).

Voting or Compromise

If consensus cannot be obtained on a particular judgment, the group may choose to vote or compromise on an intermediate judgment in AHP. This concept works with the AHP methodology because pairwise comparison's redundancy assures that priorities change very little when small changes are made to anyone's judgment. When group members understand this concept, they are capable of compromising instead of getting bogged down on a particular judgment (Dyer & Forman, 1992).

Geometric Mean

Geometric mean (averaging) can be applied for cases where consensus cannot be obtained, and the group is unwilling to vote or to compromise on the judgment. Geometric mean uses stakeholder's judgment to calculate a combined result to provide an overall judgment of the stakeholder with all stakeholders' inputs considered equal.

Applied Theories in Decision Making

Axioms for Group Decision-Making

The five most common social choice axioms that exist with AHP decision-making include:

- Axiom 1 (Universal Domain): When considering group input, the aggregation of judgments will provide a group preference pattern for all logically possible individual preferences. A group preference can be developed for any particular set of individual preferences.

- Axiom 2 (Pareto Optimality): If A and B are the two alternatives under consideration by a group and if all group members prefer A to B, then the group decision should be in favor of A.
- Axiom 3 (Independence of Irrelevant Alternatives): If an alternative is eliminated from consideration, then the new group ordering for the remaining alternatives should be equivalent (same order) to the original ordering for the same alternatives.
- Axiom 4 (Non-dictatorship): No individual preference can automatically become the preference of the group, independently of the preference of the other group members. The group pattern of preference should be arrived at only when all members' preferences have been considered. No individual's preferences should be neglected while computing group preferences.
- Axiom 5 (Recognition): Group preferences are arrived at only after considering all member preferences.

The five axioms are considered by researchers to be applicable in a variety of group decision-making environments, though there has been some disagreement between researchers that extreme divergence of opinions among group members should be avoided. The Pareto optimality axiom (Axiom 2) is almost universally accepted. (Ramanathan & Ganesh, 1994).

Separate Models or Players

If group members have significantly different objectives or outlooks, or cannot meet to discuss the decision, each group member or perhaps each sub-group, can make judgments separately. Questionnaires, protocols, and nominal group techniques can be used with a method to structure the system being evaluated and/or to make judgments. Judgments made by individual group members can be accommodated and processed in either of two ways:

- **Separate Models:** Each group member enters judgments into a separate model. The priorities resulting from these models can be averaged.

- **Players:** A combined model consisting of a level of players below the goal node is constructed. The criteria and attributes below each player need not be the same. Each group member evaluates those factors in their part of the combined model. If using a player's level in an AHP model, consideration must be given to the weights attached to the players. This can be done in any to the following four ways:
    - Each player is assumed to be equally important. This assumption is similar to the separate models, although this assumption may be represented as a "what-if" perspective and is seldom a reasonable assumption.
    - Players are assumed to be equally important, but a sensitivity analysis can be performed to investigate the effect of varying player importance. If there is no significant effect, then the equal player importance assumption is adequate even though not realistic.
    - Pairwise comparison of the relative importance of the player can be made, but the question of who makes judgment can be controversial.

AHP can derive the priorities of several individuals according to the soundness of their judgments. The factors affecting these include years of experience, relative intelligence (which is difficult to qualify), past record, depth of knowledge, experience in related fields, personal involvement in the issue at stake, etc. This can be accomplished as a part of an AHP model or in a subsidiary AHP model constructed for evaluating player importance (Dyer & Forman, 1992).

Non-Common Consensus

Consensus cannot always be met in situations where parties (or groups of parties) have non-shared, or sometimes hidden objectives. For this situation, AHP driven approaches help the parties to focus on interests (objectives) rather than positions (alternatives). Groups that focus on interests rather than positions, since interests really define the problem and potential solutions, will reconcile interests rather than positions. AHP provides the framework and structure of an evaluation (Dyer & Forman, 1992).

Aggregation of Judgments and Aggregation of Priorities

Geometric mean is used in situations where consensus and compromise are not possible. Two aggregation methods or ways to combine stakeholder input, utilized are aggregation of judgments (AIJ) and aggregation of priorities (AIP). When individuals are willing to or must relinquish their own preferences (for values and objectives) for the good of an organization, they act in concert. Their judgments are pooled to allow the group to act as a new "individual." Individual identities are lost with every stage of aggregation, and a synthesis of the hierarchy produces the group's priorities. Though individual identities are lost, the hierarchy is maintained for each cluster of elements where an individual judgment was made. Often, evaluation is not concerned with individual priorities because each individual participates and provides judgments as part of the judgment process for every cluster in the hierarchy (Forman & Peniwati, 1998).

Steps need to be taken to aggregate the resulting information to evaluate the preference of the entire stakeholder group as well as subgroups. Stakeholders' aggregation can be achieved by 1) aggregating the individual judgments for each set of pairwise comparisons into an aggregate hierarchy, 2) synthesizing each of the individual's hierarchies and aggregating the resulting priorities, and 3) aggregating the individual's derived priorities in each node in the hierarchy. In this assessment, the relative importance of the stakeholders can be assumed to be of equal importance or else incorporated in the aggregation process (Forman & Peniwati, 1998).

Three procedures which can be used for aggregation:

- Procedure 1: The stakeholder group must unanimously agree upon criterion weights or allow them to be allocated to those who appointed the decision-making group initially. Then, the group jointly assess the alternatives in light of these criteria and their weights.

- Procedure 2: Each stakeholder comes to his or her own conclusion independently of other group members regarding the alternative scores. This may be done after allocating their own criterion weights. After, the stakeholder group merely aggregates the final scores of the member to arrive at the group view of the alternatives. Multiplicative AHP is used to determine the group preference scores for both of these methodologies are considered identical only when each group member arrives at the same weighting for each criterion.
- Procedure 3: Composite group criterion weights are aggregations of the row elements of a pairwise comparison matrix, whose elements are actually aggregations of individual stakeholder's pairwise comparison amongst criteria. Also, the elements of the pairwise comparison matrices for assessing alternatives under each criterion are composed of a geometric mean aggregation of individual group members' assessments. This model creates a single composite stakeholder whose criterion weights are a compromise of all the group members' weights as well as a-composite of the pairwise assessments.

Procedure 4 utilizes AIJ, which is a synergistic aggregation of individual judgments that require stakeholders to relinquish their personal preferences for the good of an organization. AIJ requires that stakeholders work together as a group to agree on a common hierarchy before aggregating their judgments. The process of hierarchy agreement is the first step to combining the different stakeholders into a new representative group. AIJ occurs at the judgment level when the hierarchy is assessed and when evaluating the relative importance of the criteria. Once the process is complete, the previous individual judgments become irrelevant. Procedure 2 involves AIP, which allows each stakeholder to act individually with differing value systems (Forman & Peniwati, 1998). Once an evaluation is completed, the calculated priorities can be combined to find a representative priority for the group. (Forman & Peniwati, 1998).

Inconsistencies

If individual stakeholder inconsistencies are found, the group can ask an individual to consider revising one or more judgments. The group can also decide to exclude an individual's judgment from the evaluation if the inconsistency ratio is too high (Forman & Peniwati, 1998). If there are no set ways to weight stakeholders, the consistency ratio can be used to weigh each stakeholder's assessment. Allocation based on a consistency ratio may allow for a more objective decision to be made. The consistency of ratio and Euclidian distance are calculated at the criteria and alternative level. They are then combined to assign weights on the local hierarchy level. In the test case provided, the prioritization of using the standard and constancy ratio method was similar, with a minor difference in the values, not the ranking (Srdevic, Blagojevic, & Srdevic, 2011).

Integration of Streamlined Life Cycle Assessment with Multicriteria Decision Analysis

DecisionTogether© integrates SLCA and AHP to provide an inclusive decision-making methodology. Specifically, this integration allows for an environmental system to be methodically defined and evaluated. Unlike GDM methodology that relies mainly on expert input, DecisionTogether© provides for an inclusive means for a diverse group of stakeholders to interact and participate in the decision-making process. DecisionTogether© works to develop consensus and does not intend to select the final environmental system. The methodology provides a well-guided process in which to develop criteria and alternatives which are important for the evaluation of a goal/objective. The DecisionTogether© process is repeatable to allow for refinement of the evaluation process. A diagram of the integrated environmental decision tool is presented in Figure 34.

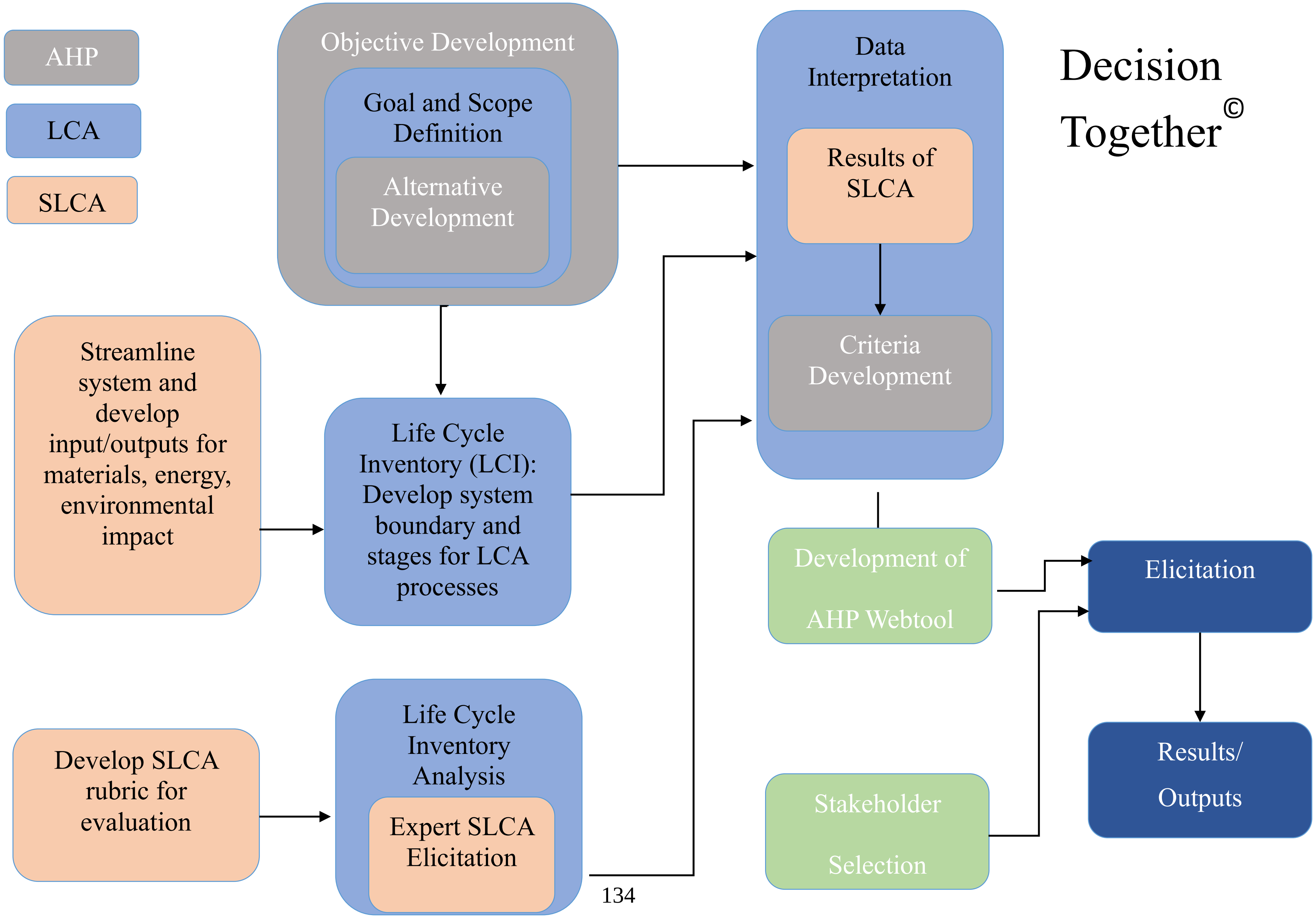

Figure 34: DecisionTogether© Methodology Overlay

The development of the integrated methodology is described below. LCA requires four steps, as outlined in ISO 14040, which include:

1. Goal and scope definition
2. Life Cycle Inventory (LCI)
3. Life Cycle Inventory Analysis (LCIA)
4. Data interpretation

To maintain the integrity of the LCA process, SLCA must follow the LCA evaluation. AHP involves three steps:

1. Defining the objective
2. Selecting the alternatives
3. Selecting the criteria

The process of defining AHP's objective and SLCA's goal and scope definition are combined to define the system being considered and the reason for the evaluation. The alternatives are selected based on this evaluation. Since this methodology was developed with evaluating potential future environmental systems in mind, SLCA allows for the simplification of the LCI and LCIA steps of LCA. SLCA aids in system boundary development and the simplification of the life cycle stages within the system boundary for evaluation. ERPA and its 5x5 matrix are used to determine the environmental impacts of the system.

The five most critical or most important life cycle stages are retained. Five environmental impacts categories are evaluated. The reduction in life cycle stages and environmental impacts allows for the collection of a reduced amount of information since limited data may be available. SLCA can be developed for similar systems considered as alternatives for the AHP evaluation. SLCA evaluation requires expert input instead of databases for the evaluation of impacts as compared to the life cycle stages. These experts can be part of the stakeholder group holder utilized in the AHP evaluation. SLCA cannot rank multiple criteria but can inform the environmental criteria considered in the AHP process. AHP allows for additional criteria to be evaluated and prioritized, along with alternatives.

The AHP is utilized to develop local priorities of the stakeholders as individuals and as a group. Once the elicitation process is complete, the group preference, as well as subgroups of stakeholders who participated in the elicitation, can be aggregate. Aggregation can be achieved in several ways when more than one individual participates in a decision process, such as 1) aggregating the individual judgments for each set of pairwise comparisons into an aggregate hierarchy, 2) synthesizing each of the individual's hierarchies and aggregating the resulting priorities, and 3) aggregating the individual's derived priorities in each node in the hierarchy. DecisionTogether© assumes that each stakeholder has an equal voice the elicitation process and are incorporated equally in the aggregation process.

For any given elicitation, the developer must set the goal of the particular elicitation session. The first elicitation activity involves collecting background information regarding the organization for which the evaluated environmental system. Next, the developer works on the extraction of individual requirements and begins to consider the appropriate elicitation session techniques. The best elicitation technique should be based on research and already acquired knowledge. Additionally, the developer must consider the available elicitation software to use in the elicitation process (Ayalew & Masizana, 2009).

DecisionTogether© integrates these concepts and enables elicitation through the development of a web application and associated documentation, providing the stakeholder with an interface of the SLCA and AHP methodology by the framing of, collecting of inputs, and evaluation of an environmental system. The DecisionTogether© web application is accessed at decisiontogether.com.

The DecisionTogether© methodology provides a simple means to elicit input from a variety of stakeholders to determine stakeholder priorities. As discussed previously, the stakeholder engagement process requires the following elements:

- Establishing a clearly defined environment system defined using SLCA who's impacts and alternatives can be assessed using AHP.
- Establishing a common understanding of the problem or question to be evaluated.
- Providing an accessible means to collect multiple stakeholder input.
- Providing a means to evaluate the outputted data for evaluation.
- Providing an output to facilitate stakeholder engagement and discussion.

The DecisionTogether© web application is designed and implemented with the Vue.js framework and Firebase for database and deployment. Vue.js is an open-source JavaScript framework to allow for developing user interfaces and single-page applications ("Vue.js," n.d.). Firebase is a hosted NoSQL database that allows for the storage and syncing of data between users in real-time ("Firebase," n.d.). The web application allows each stakeholder to complete the pairwise comparisons required for the AHP process. The web application contains three parts: Part 1: pairwise comparison of criteria with respect to the objective/goal, Part 2: pairwise comparison of criteria attributes with respect to each criterion, and Part 3: pairwise comparison of alternatives with respect to each criterion. The stakeholders' interface with a series of screens, one for each pairwise comparison. For each part, by hovering the cursor over the box containing the criteria/attributes/alternatives, the stakeholder can easily access the explanation of concept to be considered. A slider is implemented for the user to numerically choose their preferences for the pairwise comparison, and they can justify their preferences in the comment box. A document is available for download via a link to the upper right corner of each webpage. The text from the development from DecisionTogether© is in Appendix D.

As the stakeholders submit their entries, the web application calculates their preferences and consistencies of their answers and stores the data into Firebase. Each part creates comparison matrices, which is then filled with stakeholders' input, and then used for calculations. The data stored can be downloaded as a comma-separated values (CSV) file, conveniently accessing all the stakeholders' inputs, preferences, and consistencies. The CSV file can be accessed using Microsoft Excel.

Conclusion

DecisionTogether© provides the methodological means to SLCA and AHP in a format that can be used for the elicitation of diverse stakeholders. SLCA is used to frame the environmental system to be evaluated. SLCA allows for the LCA process to be streamlined to allow for use in the development and conceptual phase of an evaluation. SLCA is then integrated with AHP to provide a means to guide the stakeholders through the evaluation of criteria, attributes, and alternatives. DecisionTogether© integrates SLCA and AHP and has a web-based interface that allows for stakeholders to participate together or remotely. In Chapter V, DecisionTogether© will be applied to evaluating end of life municipal solid waste systems with participation from diverse stakeholders.

CHAPTER V

Application of DecisionTogether©

Application of DecisionTogether© for Municipal Solid Waste Planning

DecisionTogether© integrates Streamlined Life Cycle Assessment (SLCA) and Analytical Hierarchy Process (AHP) to create an inclusive decision-making methodology that is accessible and usable for diverse stakeholders. DecisionTogether© aids in the development of priorities and areas of consensus during the evaluation of environmental systems. In this section, DecisionTogether© is applied to evaluating future end of life residential Municipal Solid Waste (MSW) management in Middle Tennessee. As discussed in Chapter IV, DecisionTogether© integrates the four steps of LCA (goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and data interpretation) through the use of SLCA with the three steps of AHP (defining the objective, selecting the alternatives, and selecting the criteria). The SLCA and AHP processes begin with the definition of the goal and scope, which translates into the goal of the evaluation. For this application, the goal/objective is to determine which future end of life residential MSW management system is preferred for Metro Nashville.

Definition of System Boundaries

The system boundary for the evaluation for Metro Nashville is shown in Figure 35. System inputs include MSW and energy, and the outputs include impacts to water, impacts to land, impacts to air, and energy. Since this evaluation is hypothetical, there is limited quantitative data available. Therefore, the majority of the evaluation uses qualitative data.

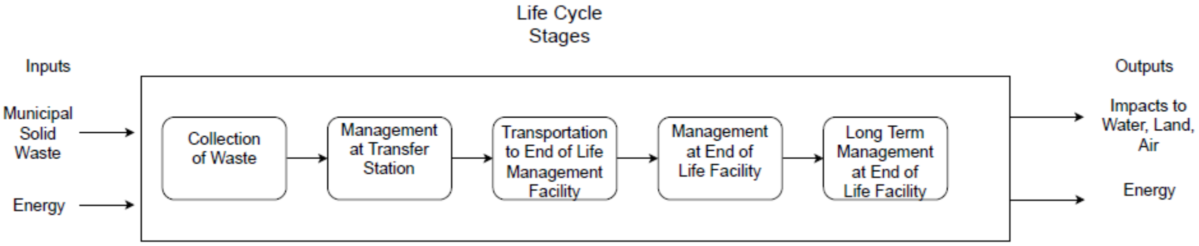

Figure 35: Streamlined Life Cycle Assessment

Stakeholder Selection

Stakeholders in the decision-making process should have an interest in the evaluated goal, scope, and objective. Two main groups of stakeholders exist: standard stakeholders and interest groups. Standard stakeholders are those with legitimate responsibility to participate in the decision-making process and include decision-makers, experts, planners, and analysts. Stakeholders can also include elected officials or municipal administrators. Stakeholders may have other full-time jobs or commitments, which can limit their time to devote to the decision-making process. There is also variability in the stakeholder's knowledge of environmental questions, and their ability to understand the causal relationship between different impacts may vary significantly. Interest groups include political parties, civic organizations, or residents of the area impacted by the environmental system. Each interest group has its viewpoint for evaluating potential alternatives and often has different relational systems of preference. Interest groups can have varying views on objectives and alternatives and add a sociopolitical dimension to the process (Lahdelma & Hokkanen, 2000). Successful decision-making needs to consider stakeholder’s real points of view. Criteria for decision making may only be identified when all stakeholders’ points of view are recognized.

For an MSW treatment plan study in Boston, Massachusetts, Contreras et al. (2008) divided stakeholders into three groups: 1) governmental agency, 2) pro-environmental, non-governmental organizations, and 3) area residents. The study includes residents because of their important role in the waste separation and implementation of the MSW plan at the residential level. The private sector was not considered in this study because of its potential to focus on the ranking of alternatives based on economic issues and other criteria (Contreras et al., 2008). In another assessment of waste management scenarios in Nis, Serbia, only workers in the waste management sector were utilized. In this case, only environmental impacts were considered in the AHP evaluation, with stakeholders being provided the results of the Full LCA data to aid their AHP evaluation.

In the evaluation of future waste management systems in Naples, Italy, local stakeholder groups, including policymakers, voters, political parties, experts, associations, non-governmental organizations, and grassroots movements, were involved in the data validation stage to determine if the system evaluated was adequate and to discuss the relevant performance indicators and policy options. The study found that the engagement of stakeholders from time to time was useful in providing suggestions and input in the decision-making process (Chifari et al., 2017).

A variety of potential stakeholders participated in the evaluation of end of life MSW management systems in Metro Nashville. Stakeholder groups were selected based on a literature review as well as based on the knowledge the author.

The stakeholder types utilized in this study include:

- Regulators
- County/City Government Officials
- Solid Waste Authority/County Solid Waste Director and/or Operators
- Academics
- General Publics
- Corporate Landfill Manager/Operators
- Others (self-identified)

Criteria/Attribute Development

Criteria and attributes developed are based on the goal and objective of the decision-making process. Multicriteria Decision Analysis (MCDA) use allows for conflicting criteria relevant to a problem to be evaluated in a systematic way (Ekener 2016). Zanghelini et al. (2018) found that environmental criterion, framed by LCA, was the most utilized criterion for assessment in MCDA along with economic, social, and technical criteria. There may be overlap between criteria. For example, ecoefficiency was seen as an overlap between environmental and economic criteria. Sustainability is considered as an overlap between environmental, economic, and social criteria (Zanghelini et al., 2018).

In assessing waste management scenarios using energy recovery, LCA and MCDA evaluated alternative systems, only considering the environmental criterion divided into LCA impact attributes (abiotic depletion, global warming, human toxicity, photochemical oxidation, acidification, and eutrophication) (Milutinovic et al., 2017). In evaluating sustainable waste to energy technologies for solid waste treatment, the criteria included quantitative and qualitative environmental, economic, and social. The environmental criterion was further divided into the attributes of abiotic depletion, stratospheric ozone depletion, summer smog, acidification, human toxicity, and ecotoxicity. The economic criterion evaluated the attributes of future costs and benefits. The social criterion evaluated attributes such as proximity to the residential area, workers' and neighborhood's safety, employment, affordability, public acceptability, and land use (Soltani et al., 2016).

The criteria of environmental, economic, and social performance have been evaluated at the same level of the hierarchy for comparison. The criteria included abiotic depletion, global warming potential, human toxicity, photo-oxidant formation, eutrophication, acidification, odors, treatment costs, and employees. The treatment costs criterion considered the attributes of capital and operational and maintenance costs, and the social criterion included the attributes of odor generation and the number of employees. Odors are often considered a nuisance from MSW systems and were estimated based on the output from the LCA (Antonopoulos, Perkoulidis, Logothetis, & Karkanias, 2014).

In Bosnia and Herzegovina for the evaluation of six MSW end of life management systems (including landfilling and waste processing), four criteria were considered; environmental, economic, social, and technical, and further divided into twelve attributes. The attributes of the environmental criterion included raw materials, reduction in landfilled biodegradable MSW, emissions to the environment, and hygienic conditions that impact human health. The economics criterion attributes included annual operation costs and income from recyclables. The social criterion attributes included employment, reaching the objectives of the Federal Strategy for Waste Management, and social acceptance. The technical criterion was divided into the attributes of the length of time required for the introduction of the scenario, the ability to meet the requirements in terms of maintenance, and availability of space to the accommodation of possible new equipment (Vucijak, Midzic Kurtagi C, & Silajdzic, 2016). For waste management systems in Boston, three impact categories were considered, which included economic, environmental, and social aspects. They were further divided into the attributes of operational costs, greenhouse gases released, disposal capacity of local landfills, and heath damage (loss of life expectancy) (Contreras et al., 2008).

Selected Criteria

Based on the literature review and professional understanding of current MSW issues, a set of criteria and attributes was developed, as shown in Table 23.

Table 23*:* Criteria Developed for Stakeholder Evaluation

Criterion	Attributes
Economics	Capital Investment Costs Operational and Maintenance Costs Economic Impact on Subscribers in Surrounding Communities Economic Incentives for Communities Surrounding Facility Property Values Around Facility
Environmental	Impact to Water Impact to Air Impact to Land
Social Acceptance	Employment Social Acceptance Noise/Odor
Technical Feasibility	Availability of Land for Facility Energy Consumption Energy Production Life Expectancy of Facility Distance from Community/Transfer Station Beneficial Reuse/Resource Conservation Implementability Available Infrastructure
Regulatory Acceptance	Applicable Regulations in Place Presence of Permitting System Zoning Limitations

Literature suggests that criteria should come from a stakeholder involved process. Value conflicts should be recognized because stakeholder disagreement can come from the fact that different stakeholders emphasize criteria differently (Lahdelma & Hokkanen, 2000). Stakeholders were not engaged in the initial development of the criteria and attributes but were asked to evaluate if the selected criteria and attributes were in line with current practitioners' understanding of issues in the MSW field. Stakeholder results are presented in Appendix C. Selected stakeholders participated in an anonymous online survey where they were asked ranked the criteria and attributes shown in Table 23. The thirteen stakeholders self-reported their associated MSW sector, as shown in Figure 36. Figure 37 shows the stakeholder criteria ranking.

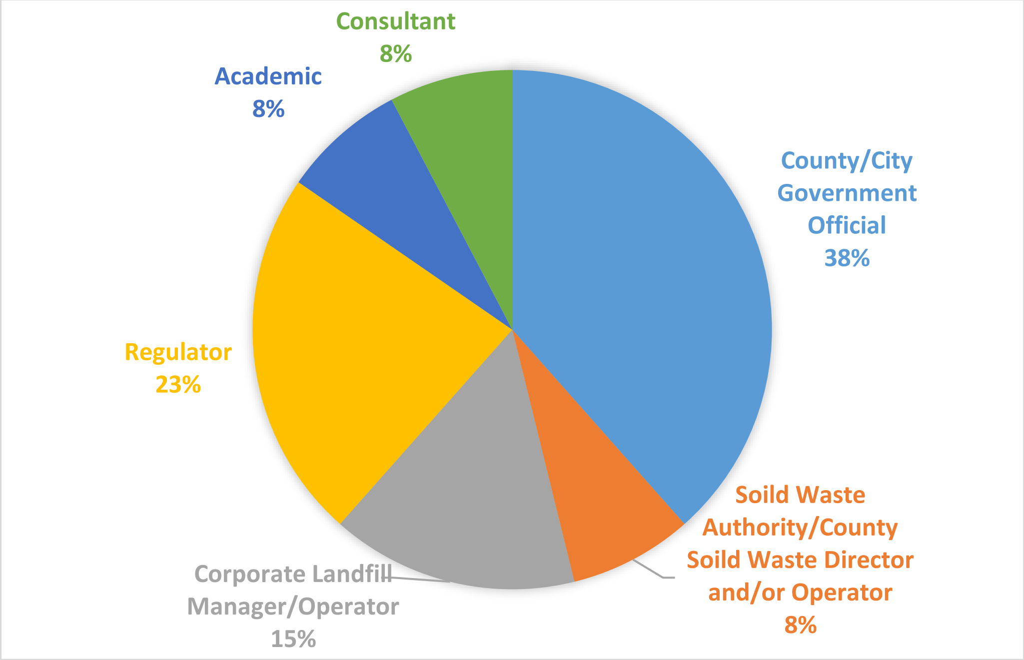

Figure 36: The Participant Breakdown by Reported Sector

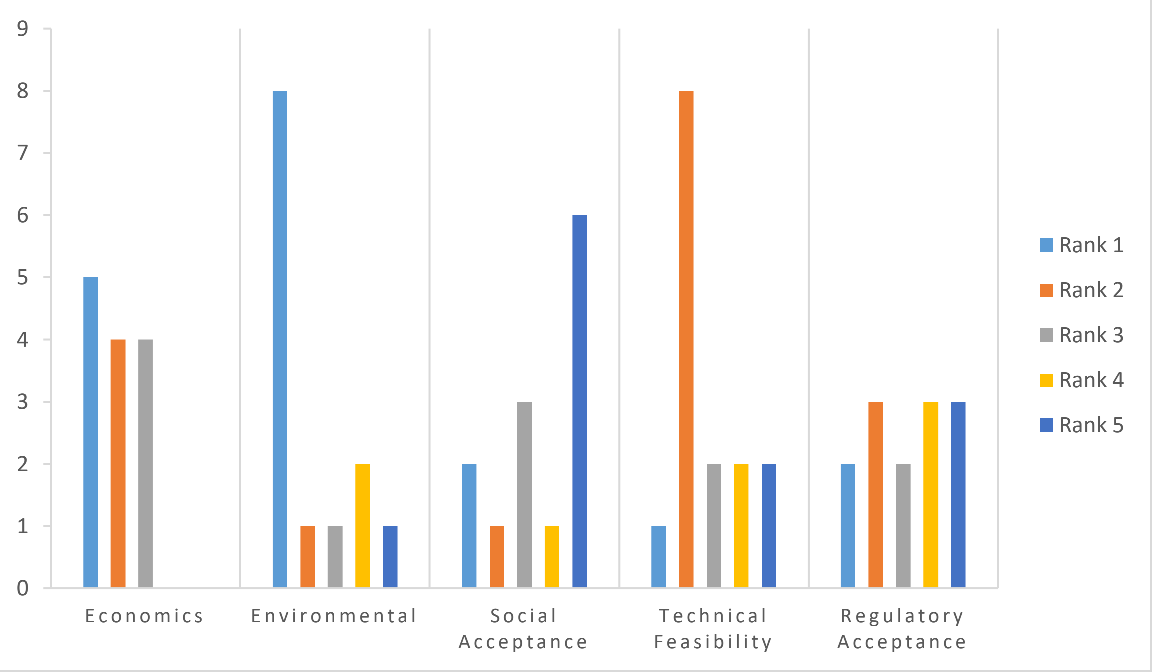

Figure 37: Ranking of Criteria

No additional criteria were identified. One stakeholder stated that all three environmental attributes should be considered equally. A survey limitation was limited to ranking criteria but did not allow a stakeholder to show equally important. One stakeholder stated that the Technical Feasibility criterion should include an attribute of technology's ability to scale up.

Table 24 presents the stakeholders' perception of the current status of planning for the future development of MSW end of life system. Stakeholders appear to have a differing opinion of the current status of future MSW systems planning.

Table 24: Stakeholder Comments for Satisfaction of Status

Comments	
I don't know enough about this to answer intelligently	I would love us to look at European methods, like Belgium or Germany.
I believe your answers will vary widely depending on the taker's knowledge of the available waste management technologies.	Solid waste management facilities have a negative reputation due to the "dump" systems in the past and poor (non-compliant) operational practices of the present. Educating citizens and government agents in a better way is needed.
Not very satisfied	Somewhat satisfied- APWA (American Public Works Assoc) should have better library or resources for those seeking help
Very satisfied as long as the process continues and does not stop until a decision is made!	Air permitting and being able to scale up economically
Somewhat satisfied. We are behind but looking into options locally.	At the present time, not very satisfied. There are limited options available currently. More incentives to develop environmentally friendly technologies need to be made available to steer away from landfilling being the predominant option in most places.

Stakeholders were also asked a question if additional barriers that prevent future development of future end of life MSW planning exist. Organizational barriers and lack of regional support were almost equal, as shown in Figure 38.

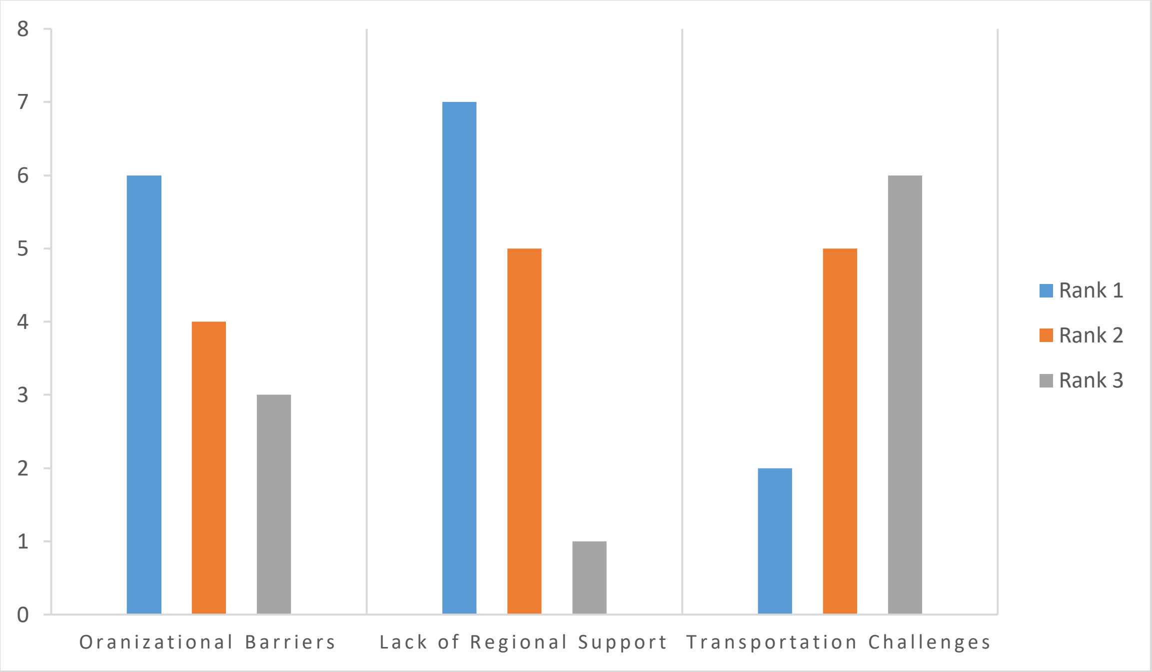

Figure 38: Evaluation of Additional Barriers

Based on the stakeholders' input, the five selected criteria are in line with the current stakeholders' perception and are used in DecisionTogether©. Minor changes to attributes intended for clarification were made, as shown in Table 25.

Table 25: Criteria Developed for Stakeholder Evaluation

Criterion	Attributes
Economics	Capital Investment Costs Operational and Maintenance Economic Incentives for Communities Surrounding Facility Property Values Around Facility
Environmental	Impact to Water Impact to Air Impact to Land
Social Acceptance	Employment Location with respect to community Noise/odor Ease of removal and management of MSW
Technical Feasibility	Availability of land/land use Energy efficiency Distance from community/transfer station Beneficial reuse/resource conservation Available infrastructure
Regulatory Acceptance	Applicable regulations Presence of permitting system Zoning Limitations

Scenario Development

Scenarios for use in DecisionTogether© were selected based on the LCA and SLCA work completed in Chapter III. In addition to landfilling, waste to energy, and MSW composting, incineration and anaerobic digestion were considered. Figure 39 presents the ranking of scenarios by the experts. MSW composting was ranked first by most stakeholders, while landfilling and waste to the energy received the next highest number of stakeholders who ranked it as first. These three alternatives were retained for evaluation during the elicitation.

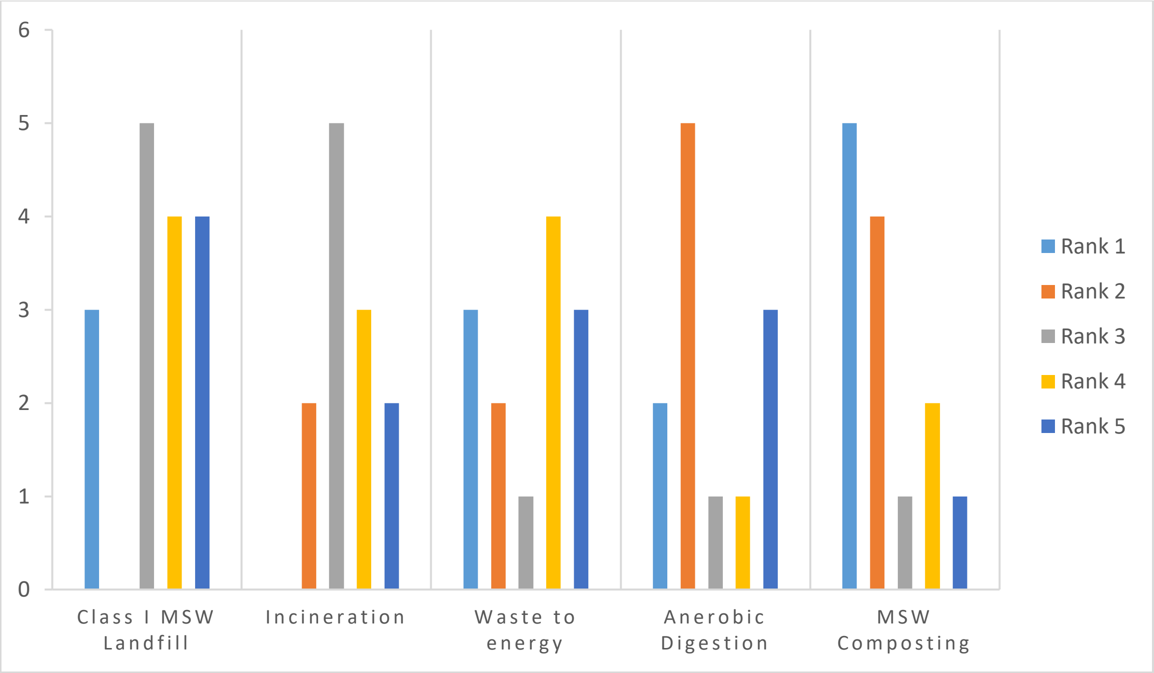

Figure 39: Scenario Evaluation by Stakeholders

When asked if any additional alternatives should be evaluated, one stakeholder said recycling should be considered. Recycling was not considered further in this work since the objective is to evaluate end of life MSW systems and not material streams removed from the MSW.

Development of Hierarchy

Based on the goal/objective, criteria and attribute development, and alternative development, the AHP hierarchy was developed as presented in Figure 40. The goal of the elicitation is to determine which end of life residential MSW management system should be implemented for Metro Nashville. The criteria are compared in a pairwise manner with respect to the goal. The attributes are compared in a pairwise manner with respect to the related criterion and the goal. Then scenarios are compared in a pairwise manner with respect to criteria and the goal.

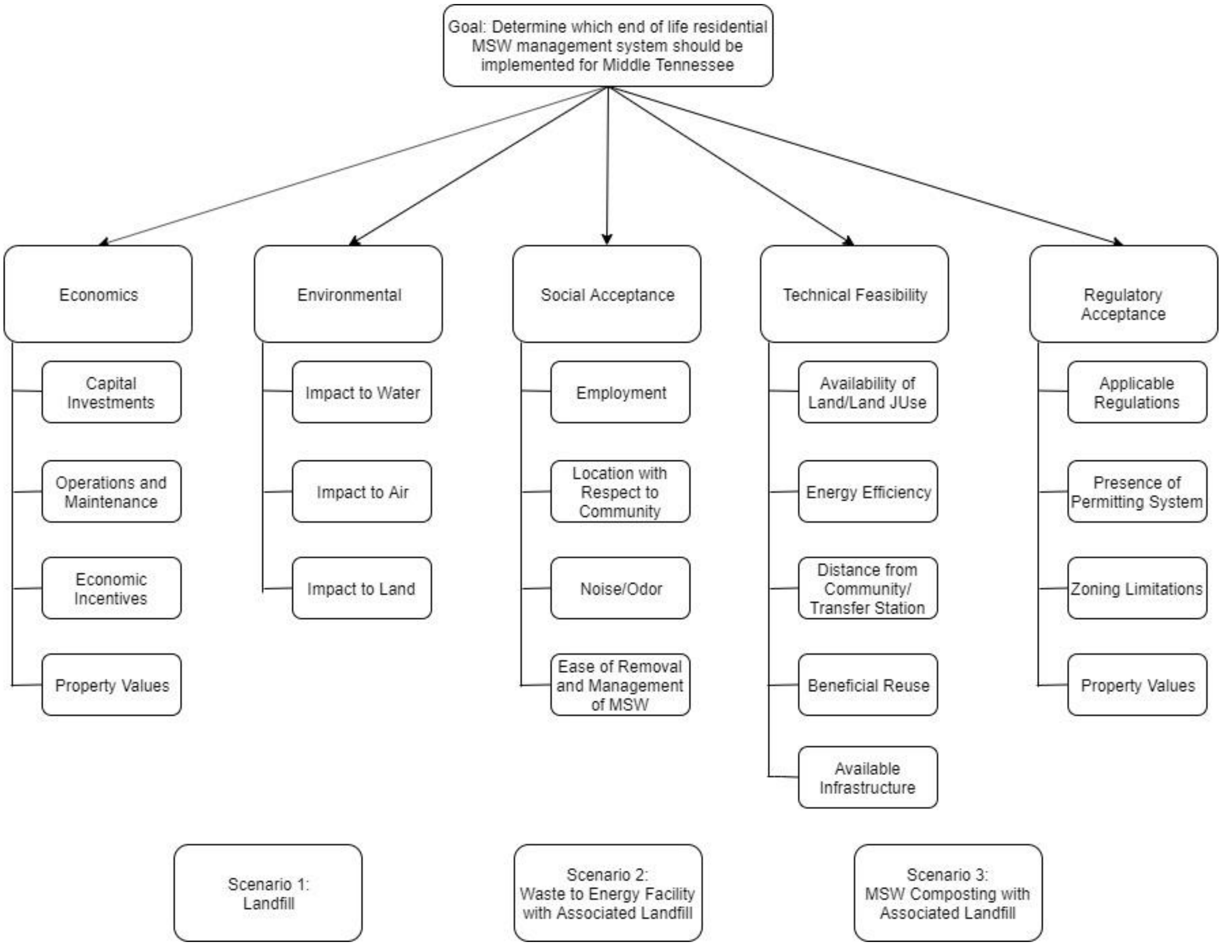

Figure 40: Hierarchy to Evaluate End of Life MSW Systems for Metro Nashville

Elicitation of DecisionTogether©

Decision Together© Background Information

The stakeholders were provided with information to help guide them through the elicitation process. The goal of the evaluation is to determine which end of life residential (MSW) management system should be implemented for Metro Nashville. To evaluate this goal, AHP will be used to compare criteria and scenarios against the goal to identify areas of consensus and disagreement between diverse stakeholders while using pairwise comparison. As discussed previously, the criteria and attributes were developed based on literature reviews and a survey with stakeholders, as shown in Table 26.

Table 26: Criteria and Attribute for Elicitation

Criteria	Attributes
Environmental	Impacts to water, air, and land
Economics	Capital investments, operations and maintenance, economic incentives for communities, property values around facility
Social Acceptance	Employment, location with respect to the community, noise/odor, ease of removal and management of MSW
Technical Feasibility	Availability of land/land use, energy efficiency, distance from community/ transfer station, beneficial reuse/resource conservation, available infrastructure
Regulatory Acceptance	Applicable regulations, presence of permitting system, zoning limitations

The three MSW management scenarios were evaluated with respect to the criteria. The system boundaries encompass residential curbside pickup, management of waste at the transfer station, transport to end of life management facility, operation at the end of life waste management facility, as well as long term management at the facility. The scenarios assume that the distance to transfer stations and the end of life waste management facility is equal for all scenarios. The scenarios considered in the evaluation include:

- Scenario 1: Landfilling
- Scenario 2: Waste to energy facility with associated landfill
- Scenario 3: MSW composting facility with associated landfill

The elicitation process was completed using the DecisionTogether© web-based application that guided stakeholders through a series of questions to complete the pairwise comparisons to determine the relative importance of one criterion or scenario with another. Judgments were made using the verbal/numerical, and scale is shown in Table 27.

Table 27: Numerical and Verbal Pairwise Judgments and Scale

Level of Importance	Definition	Explanation
1	Equal Importance	Two criteria/alternatives contribute equally to the objective
2	Weak or Slight	
3	Moderate Importance	Experience and judgment slightly favor one criterion/alternative over another
4	Moderate Plus	
5	Strong Importance	Experience and judgment strongly favor one criterion/alternative over another
6	Strong Plus	
7	Very Strong or Demonstrated Importance	A criterion/alternative is favored strongly over another; its dominance is demonstrated in practice
8	Very, very strong	
9	Extreme Importance	The evidence favoring one criterion/alternative over another is of the highest possible order of affirmation

Source: Saaty, 2008

The stakeholders were instructed to do the following to complete the elicitation:

1. Visit Website: Decisiontogether.com.
2. Input email address and sector of the waste management industry.
3. For Part 1:
    - Evaluate the criteria with respect to the goal of "which criterion is considered more important when evaluating end of life residential MSW systems for Metro Nashville?"

- Step A: Compare each criterion against the other criterion with respect to the goal.
- Step B: Select the value between one and nine to represent the degree of preference of one criterion over another. This process is achieved by sliding the scale towards the more preferred criterion.
- Step C: Provide comments in the "*provide comment"* box to provide information on the judgment that you provided. This action is highly encouraged
- Repeat Steps A, B, and C until all pairwise comparisons are made for Part 1.
- At any time, the stakeholder can navigate back to questions in Part 1, to reevaluate their responses.

4. Part 2:
    - Evaluate the attributes with respect to the criteria with respect to the goal of "which attribute is considered more important when evaluating end of life residential MSW systems for Metro Nashville?"
    - Step A: Compare each attribute against the other attribute with respect to the goal.
    - Step B: Select the value between one and nine to represent the degree of preference of one attribute over another.
    - Step C: Provide comments in the provide comment box to provide information on the judgment that you provided. This action is highly encouraged
5. Repeat Steps A, B, and C until all pairwise comparisons are made for Part 2.
6. Part 3:

- Evaluate the scenarios with respect to the criteria with respect to the goal of "which attribute is considered more important when evaluating end of life residential MSW systems for Metro Nashville?"
- Step A: Compare each scenario against the other scenario with respect to the criterion and goal.
- Step B: Select the value between one and nine to represent the degree of preference of one scenario over another.
- Step C: Provide comments in the provide comment box to provide information on the judgment that you provided. This action is highly encouraged

7. Repeat Steps A, B, and C until all pairwise comparisons are made for Part 3.

DecisionTogether© Stakeholder Selection

Stakeholder engagement was achieved in several ways. Stakeholders were contacted based on personal and professional relationships within the solid waste community in Middle Tennessee. Participation in the elicitation was completely voluntary. DecisionTogether© and its methodology were presented during the Environmental Show of the South in Chattanooga, Tennessee, in May of 2019. At the conclusion of the presentation, participants were asked to provide their contact information if they wished to take part in the elicitation. Each stakeholder was provided with an email communication outlining the process and a two-page summary for the criteria and scenarios. The information provided to the stakeholders is shown in Appendix E. Additional stakeholders were contacted via email.

Twenty-one self-reporting, stakeholders, completed the pairwise comparison for the elicitation. The breakdown of stakeholders is shown in Figure 41.

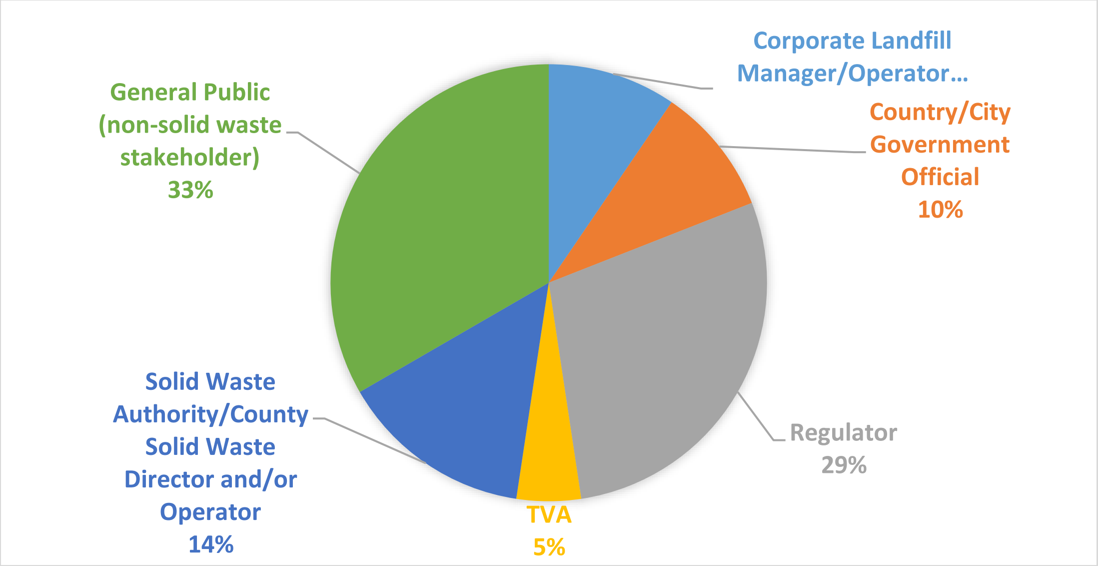

Figure 41: Sector Breakdown of Participants in DecisionTogether$^{(C)}$ Elicitation

Results of DecisionTogether© Elicitation

The elicitation results are evaluated by the following steps:

1. Determine individual priorities for Parts 1, 2, and 3 for each stakeholder.
2. Determine the Consistency Index (CI) and Consistency Ratio (CR) for each judgment for each stakeholder.
3. Combine priorities for individual stakeholders, stakeholder groups, and combined stakeholders.
4. Evaluate which stakeholders are consistent by comparing the CR.
5. Evaluate stakeholders' CI values using moving average control charts to determine if their answer pattern is consistent.
6. Combine priories for remaining stakeholder groups and all stakeholders and compare them with non-adjusted combined priorities.

7. Interview stakeholders to determine if their priorities are consistent with their understanding of the criteria, attributes, and scenarios.
8. Discuss results.
9. Make recommendations for future DecisionTogether© elicitations and stakeholder engagement.

Individual Stakeholder Priorities

As discussed in Chapter IV, the individual stakeholder priorities were calculated from the stakeholder judgments in the DecisionTogether© web application. Stakeholders were binned into three groups based on their reporting as follows:

- Stakeholder Group 1: Solid Waste Authority, County Solid Waste Director and/or Operator/ County/City Government Official, and Corporate Landfill Manager/Operator
- Stakeholder Group 2: Regulators and Other (TVA)
- Stakeholder Group 3: General Public

The "Other" stakeholder self-identified as a TVA employee and was included in the regulator stakeholder group because TVA is quasi-governmental and deemed to be most like the regulator stakeholder group. No self-reported academic stakeholders were identified. Each stakeholder was given a unique identifier to allow for anonymity. The following identifiers were used for each stakeholder sector:

- SWA - Solid Waste Authority/County Solid Waste Director and/or Operator
- CG - County/City Government Official/
- CLM - Corporate Landfill Manager/Operator
- R – Regulator

- O - Other
- GP - General Public

The stakeholders utilized pairwise comparison to evaluate Part 1: Criteria, Part 2: Attributes of Criteria, and Part 3: Scenarios.

Part 1: Criteria

The Part 1 criteria are economics, environmental, social acceptance, technical feasibility, and regulatory acceptance. Group 1 priorities are shown in Figure 42. Little consensus exists between the stakeholders. The CG stakeholders prioritized economics and technical feasibility the highest. CLM stakeholders prioritized regulatory acceptance higher than the other stakeholders, while the remaining stakeholders placed regulatory acceptance and social acceptance below the other criteria. The difference in prioritization may be due to the stakeholder's roles in the MSW community. Solid waste departments at the county and city level are organized differently and have different roles in selecting methods for waste management as well as have different financial responsibilities. SWA and CG stakeholders are also often worked between government leaders (city and county mayors) as well as the general public. CLMs are put under the same political stressors, but often have corporate responsibilities they must answer too.

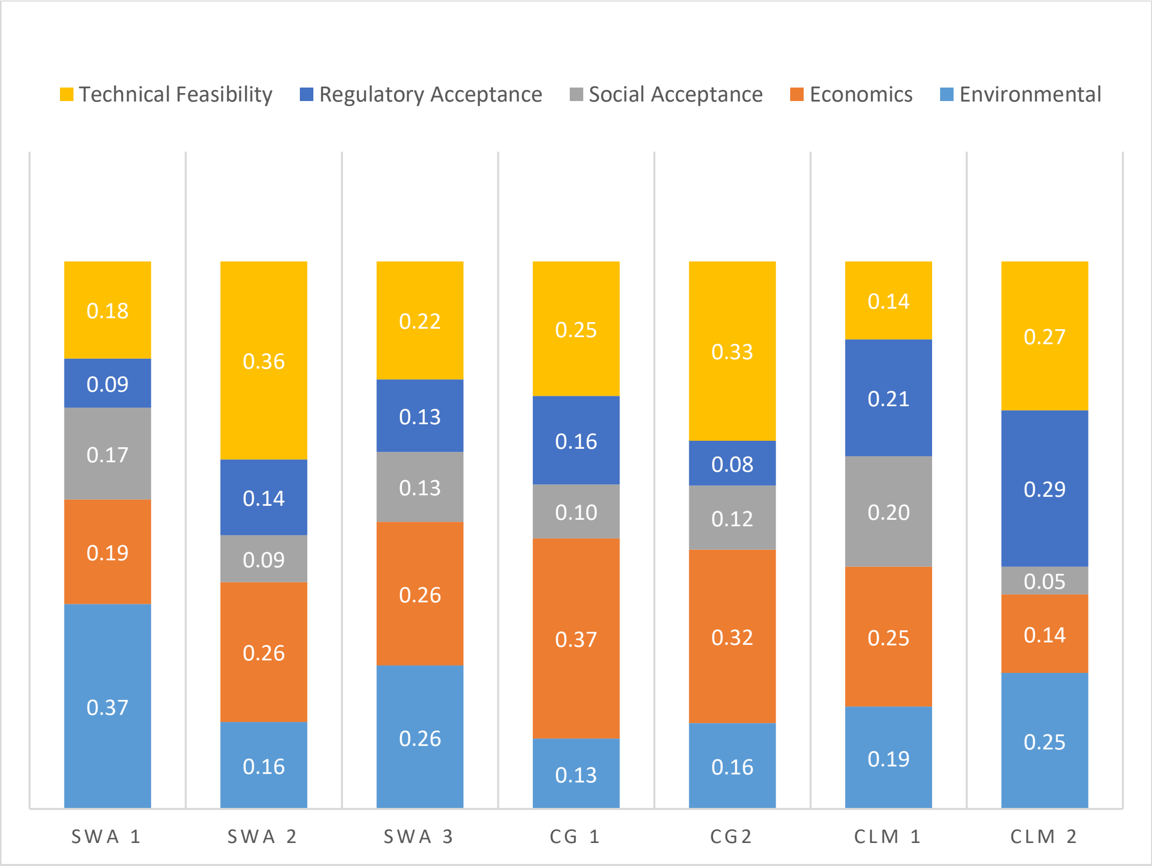

Figure 42: Part 1 Criteria Prioritization for Group 1

Priorities from Group 2 are shown in Figure 43. Little consensus exists between the stakeholders. The Other stakeholder prioritized regulatory acceptance as the highest priority as compared with other stakeholders. Regulators 1 and 2 prioritized the environmental criterion as the highest priority, while Regulators 3 and 4 ranked technical feasibility as the highest priority. Regulator 5 was the only stakeholder in this group to priorities economics as the highest priority. The difference in regulator preference may come from their background prior to being a regulator and what their role within their organization they may work. Within the Tennessee Department of Environment and Conservation, the Division of Solid Waste has many roles, such as providing community assistance through their Materials Management Division as well as providing engineering oversite for solid waste permitting. These groups may approach solid waste issues in different ways. The Other stakeholder does not deal with the permitting or installation of MSW landfills but does work with Class II industrial landfills associated with TVA facilities.

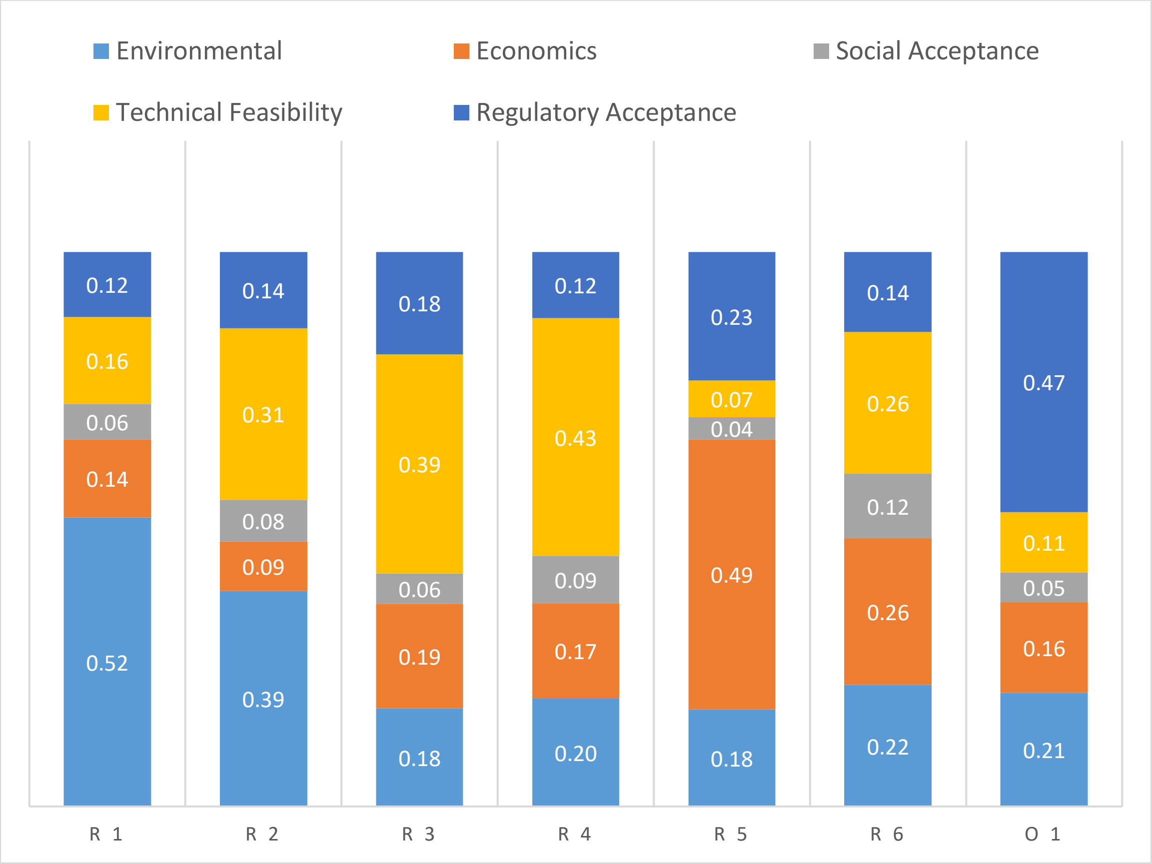

Figure 43: Part 1 Criteria Prioritization for Group 2

The priorities for the general public stakeholder group are shown in Figure 44. Of the three groups, this stakeholder group showed the least agreement in prioritization. This can be due to lots of factors. The general public stakeholders are the ones who dispose of the MSW but tend to have little interaction for the steps from transport to the final end of life management. But, these stakeholders may be impacted the most based on where a facility is sited or if there are changes to the pricing and management of curbside MSW. Additionally, these stakeholders represent the most diverse group of stakeholders. They have diverse backgrounds and understanding of technical knowledge.

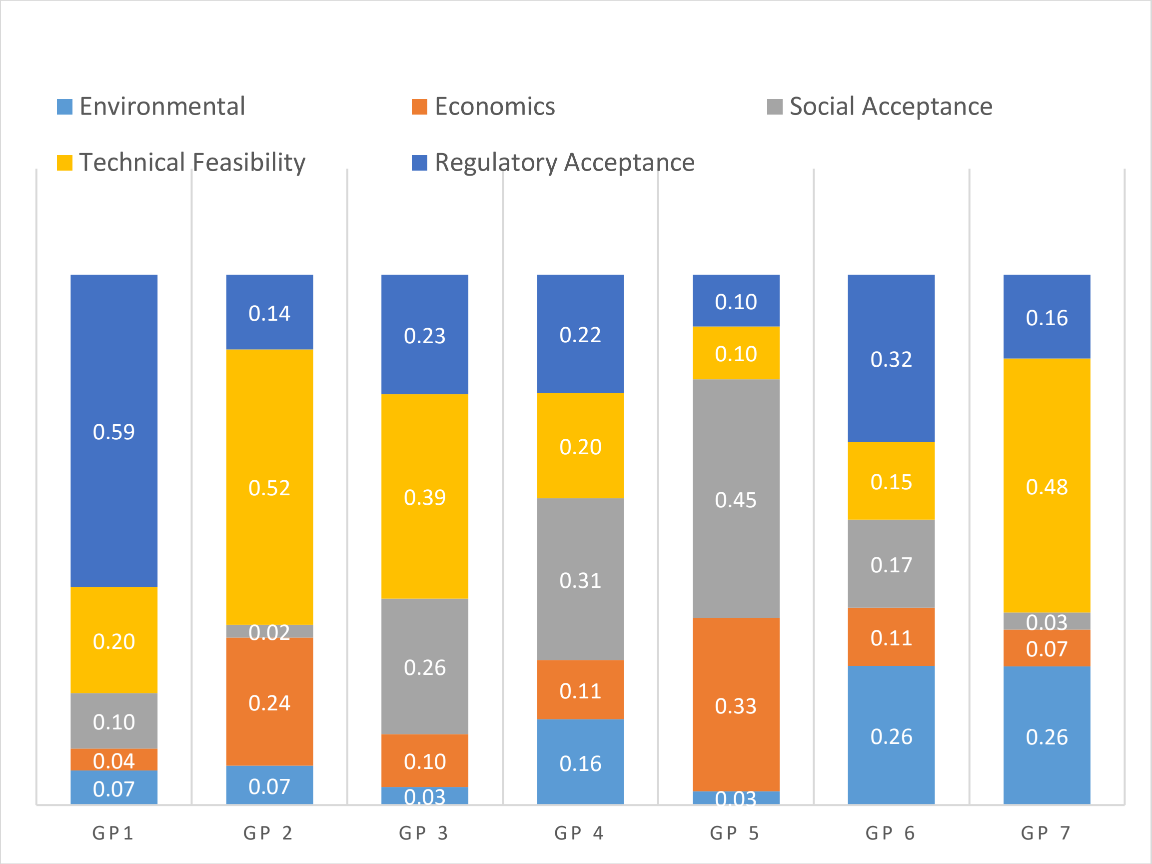

Figure 44: Part 1 Criteria Prioritization for Group 3

The priority results of the stakeholders were combined using geometric mean to develop group priorities for the three identified groups as well as the entire stakeholder group. This method utilizes the aggregation of priorities method discussed in Chapter VI. The results are shown in Figure 45. When priorities are combined, Group 1:SWA/CG/CLM and Group 2:R/O stakeholder's groups similarly prioritize their criteria, with environmental, economics, and technical feasibility as the highest prioritized criteria. When the Group 1:SWA/CG/CLM and Group 2:R/O stakeholders are combined, they have a collectively similar prioritization. This similarity could mean that if these groups worked together, they would be able to build consensus as a group. As a group, it would easy to prioritize the criteria similarly. It was expected that the GP stakeholder group would have ranked the environmental criterion as the biggest priority. In a review of the individual priorities, there was a high degree of variability, which placed technical feasibility as the highest prioritized criterion.

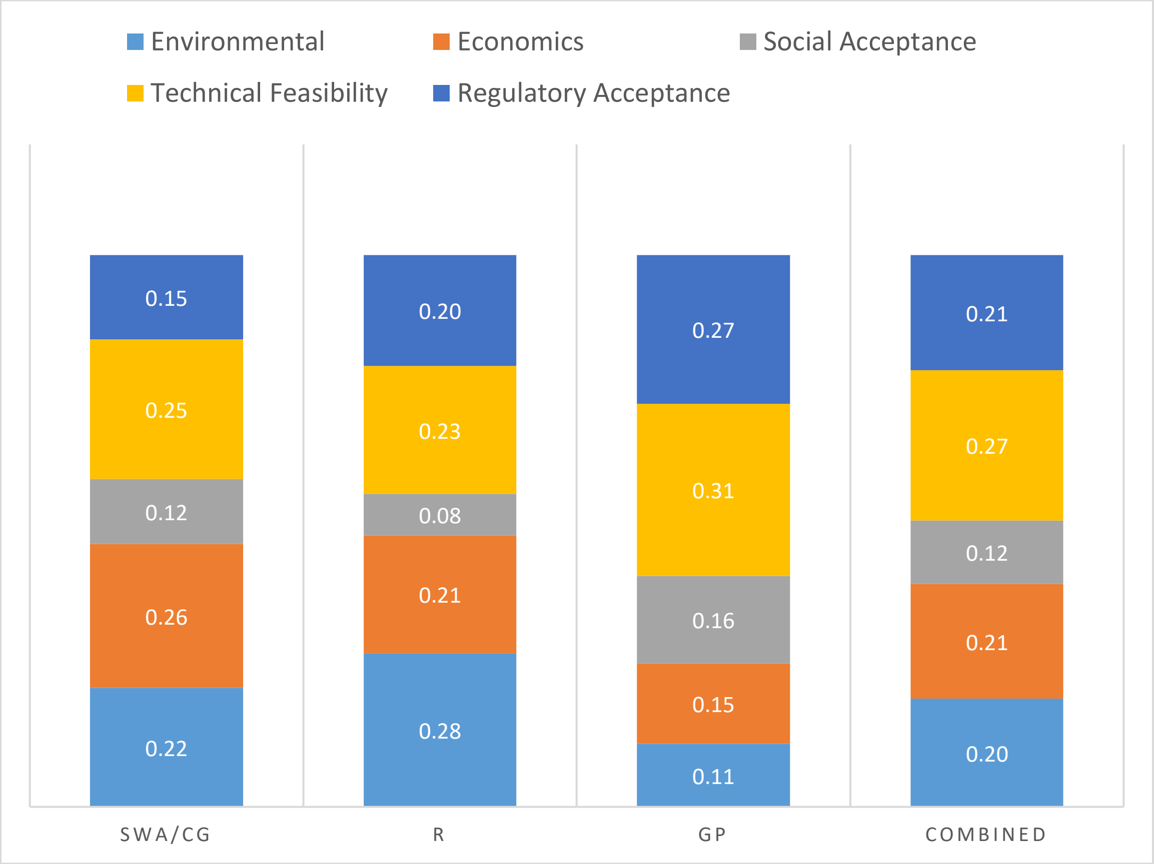

Figure 45: Part 1 Criteria Prioritization for Combined Stakeholder Groups

Part 2: Attribute Evaluation

This section discusses the results of the attribute evaluation for each criterion. Attributes were evaluated in a pairwise comparison with respect to the criterion and objective of the evaluation. Attributes were assessed for the environmental, economic, social acceptance, technical feasibility, and regulatory acceptance criteria. The evaluation of the attributes is intended to provide information on the aspects of the criteria, which are most or least important to the stakeholders. The results and discussion are provided in the following sections.

Environmental

Three attributes were evaluated with respect to the environmental criterion: impacts to air, impacts to water, and impacts to land. Figure 46 presents the results from the Group 1 evaluation. In some cases, the three attributed were ranked as having equal priorities (SWA 1, SWA 3, and CG 2).

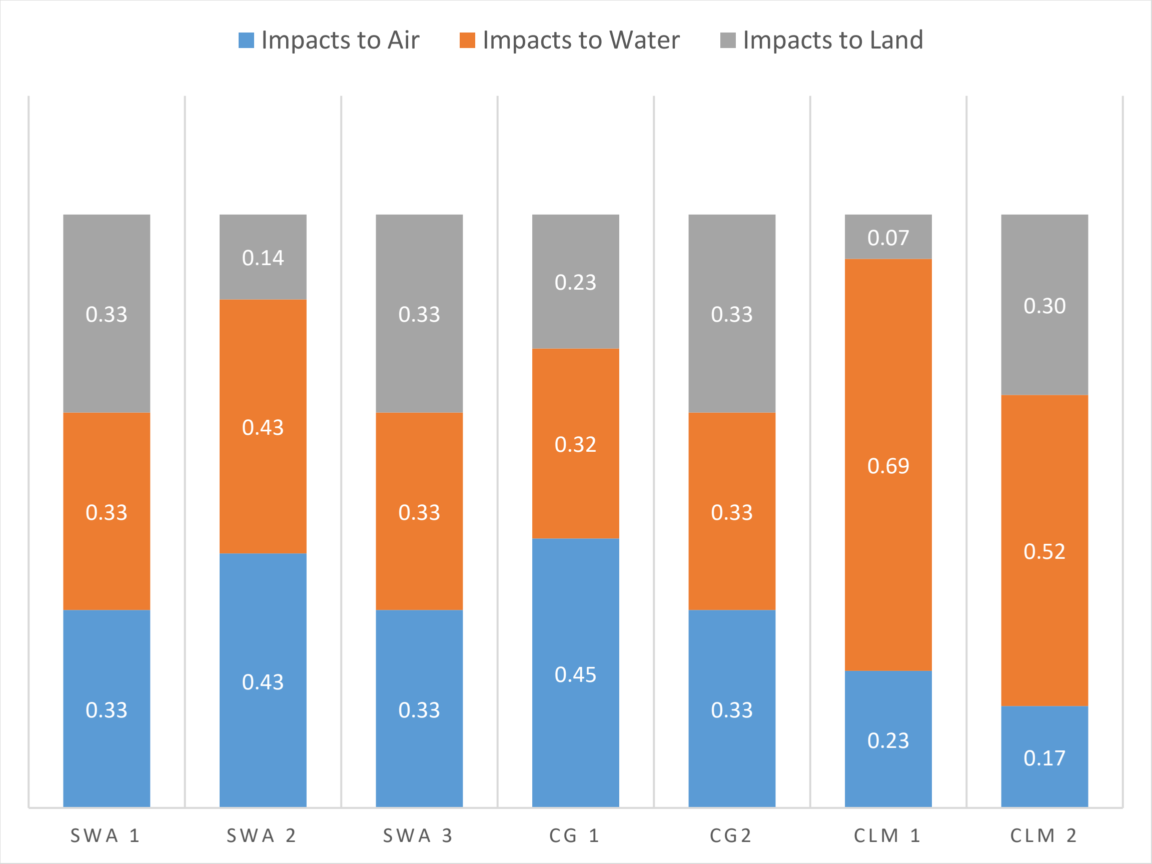

Figure 46: Part 2 Environmental Attributes Prioritization for Group 1

Figure 47 presents the results from the Group 2 evaluation. In two cases, the three attributed were ranked as having equal priorities (R 3 and R 4). Three stakeholders from this group place impacts to water above the other two impacts (R 2, R 5, and O 1).

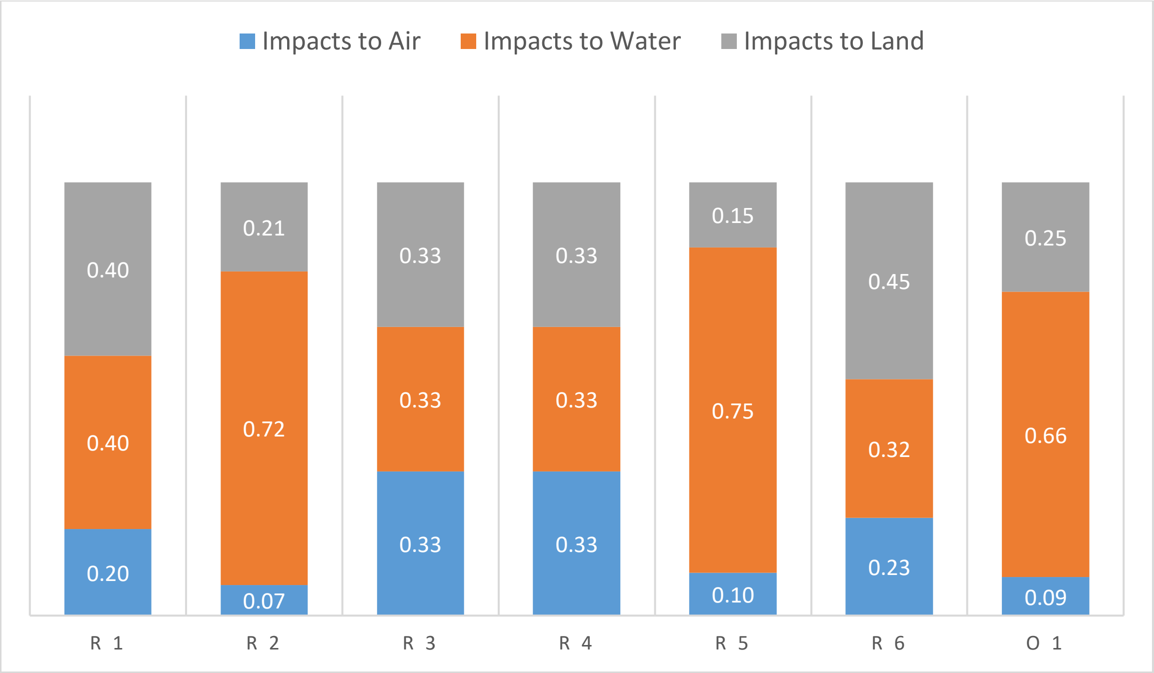

Figure 47: Part 2 Environmental Attributes Prioritization for Group 2

Figure 48 presents the results from the Group 3 evaluation. In three cases, the three attributed were ranked as having equal priorities (GP 5, GP 6, and GP 7). For the remaining stakeholders, two stakeholders prioritized impacts to land first (GP 1 and GP 2 and two stakeholders prioritized impacts to water first (GP 3 and GP 4).

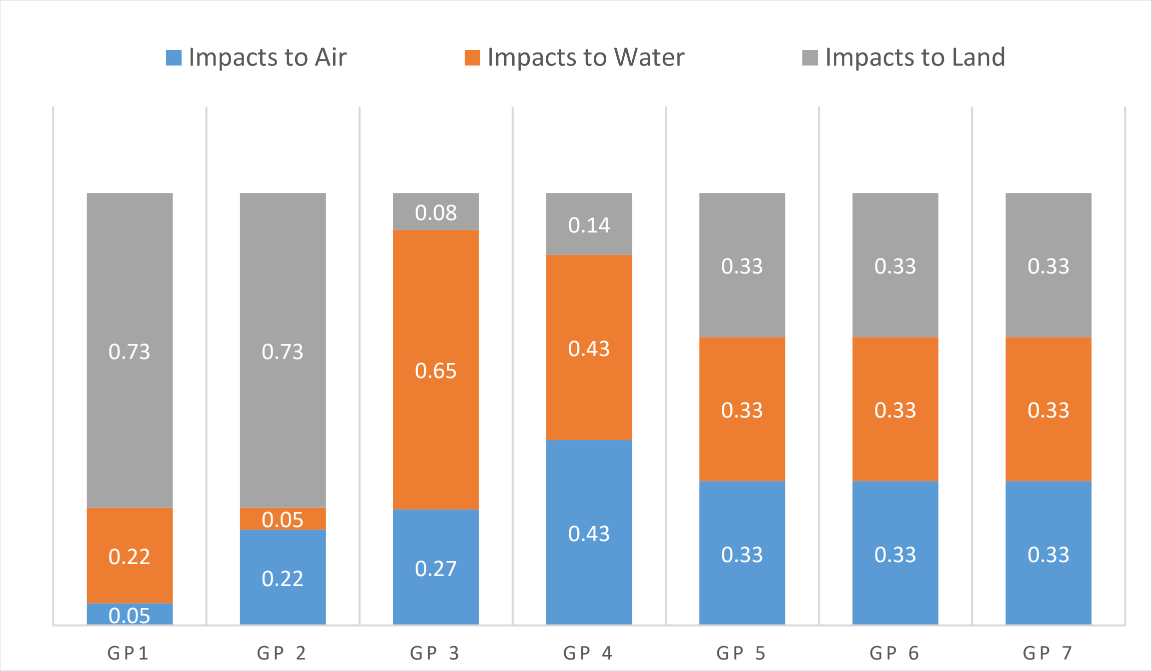

Figure 48: Part 2 Environmental Attributes Prioritization for Group 3

Figure 49 presents the combined group priorities. When combined, the Group 1 and Group 2 groups prioritized impact to water first, while the GP group prioritized impacts to land first. There was limited consensus in prioritization from the three stakeholder groups.

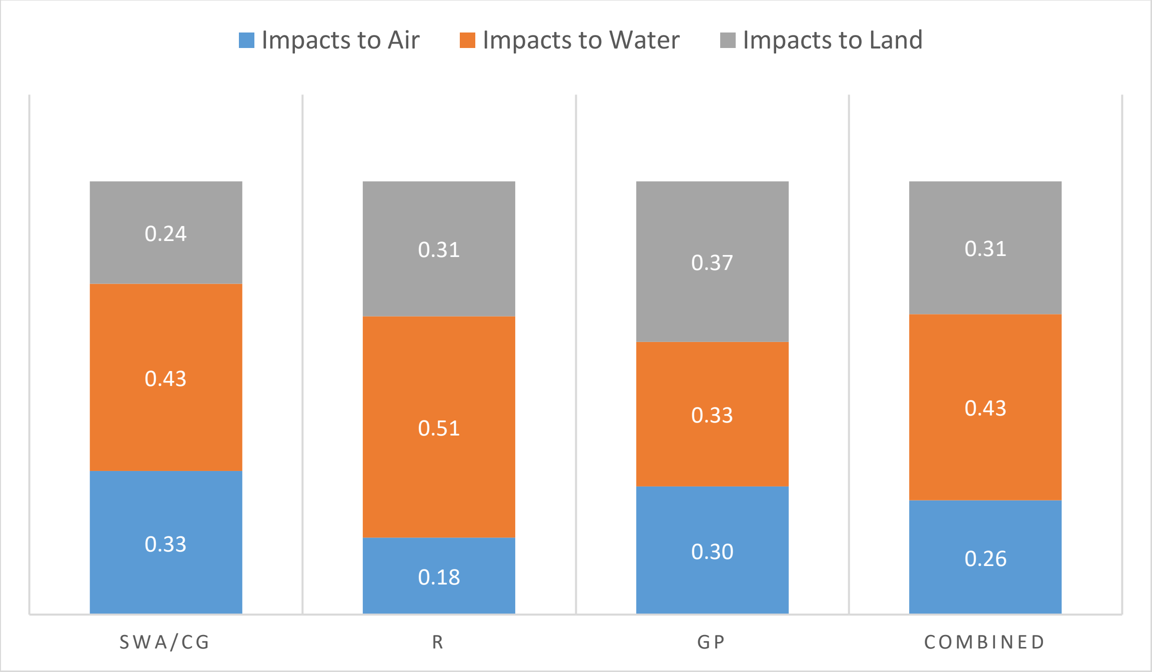

Figure 49: Part 2 Environmental Attributes Prioritization for Combined Stakeholder Groups

Economics

Four attributes were evaluated and prioritized for the Economics criterion. Figure 50 presents the results from the Group 1 prioritization for economic attributes. In four cases, the operations and maintenance attribute prioritized the highest (SWA 1, SWA 2, CG 2, and CLM 1). Often the long-term maintenance and operation costs of a facility can be uncertain and require the majority of the economic resources. SWA 3 prioritized property values around the facility first. CG 1 prioritized all of the attributes equally.

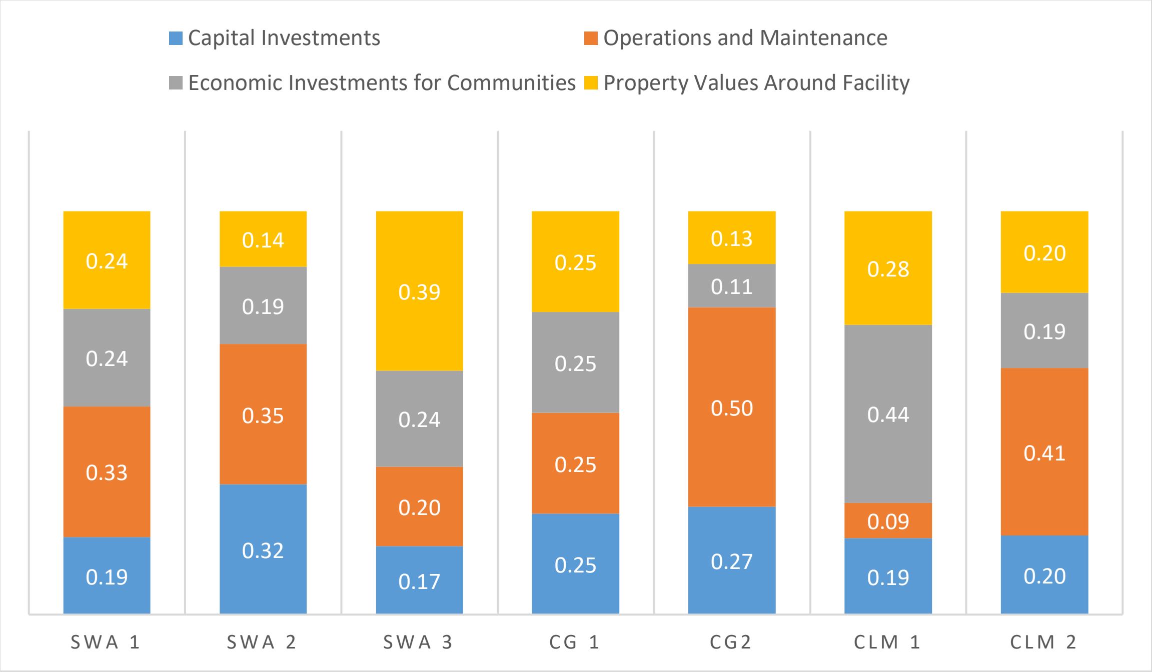

Figure 50: Part 2 Economics Attributes Prioritization for Group 1

Figure 51 presents the results from the Group 2 prioritization for economic attributes. In two cases, operations and maintenance attributes prioritized the highest (R 2 and R 3). R 4 and R 5 capital investments as the highest priority. Capital investments, along with operations and maintenance costs, can make up the greatest amount of expenditure for a facility. R 1 prioritized all the attributes equally.

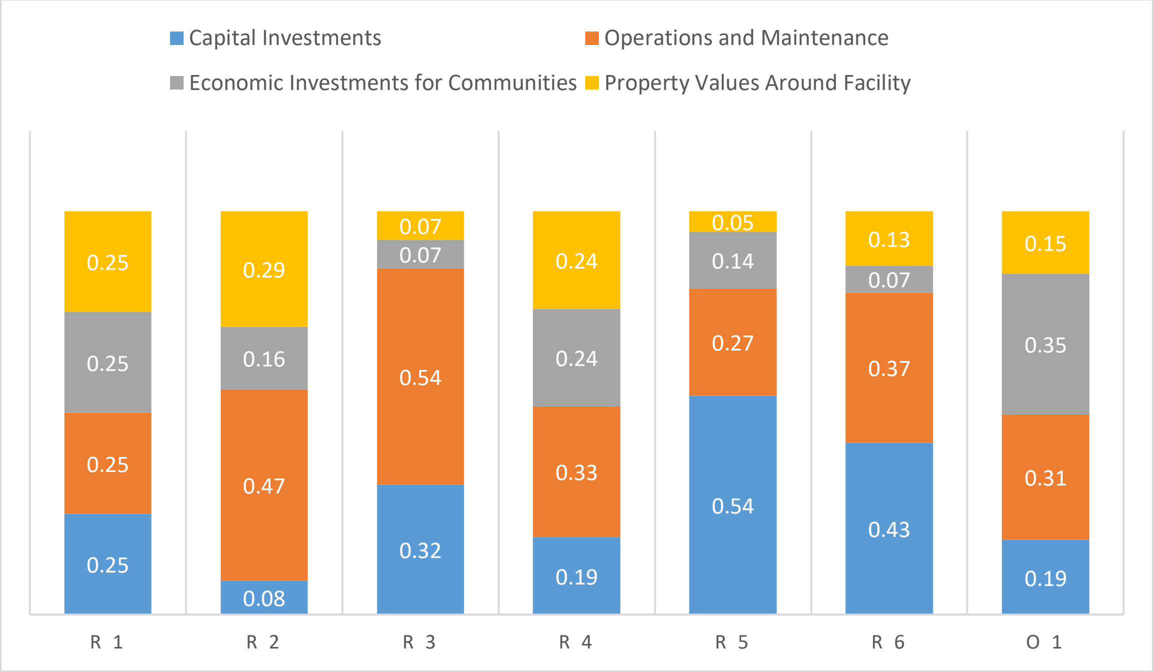

Figure 51: Part 2 Economics Attributes Prioritization for Group 2

Figure 52 presents the results from the Group 3 prioritization for economic attributes. The GP stakeholders prioritized property values around the facility as the highest priority in most cases. This is in line with potential concerns a community would have about a facility being located within their city. This economic cost, along with economic incentives for communities, is external, community-based economic attributes, since they do not necessarily involve the corporate or county costs that may be associated with the development of MSW facilities.

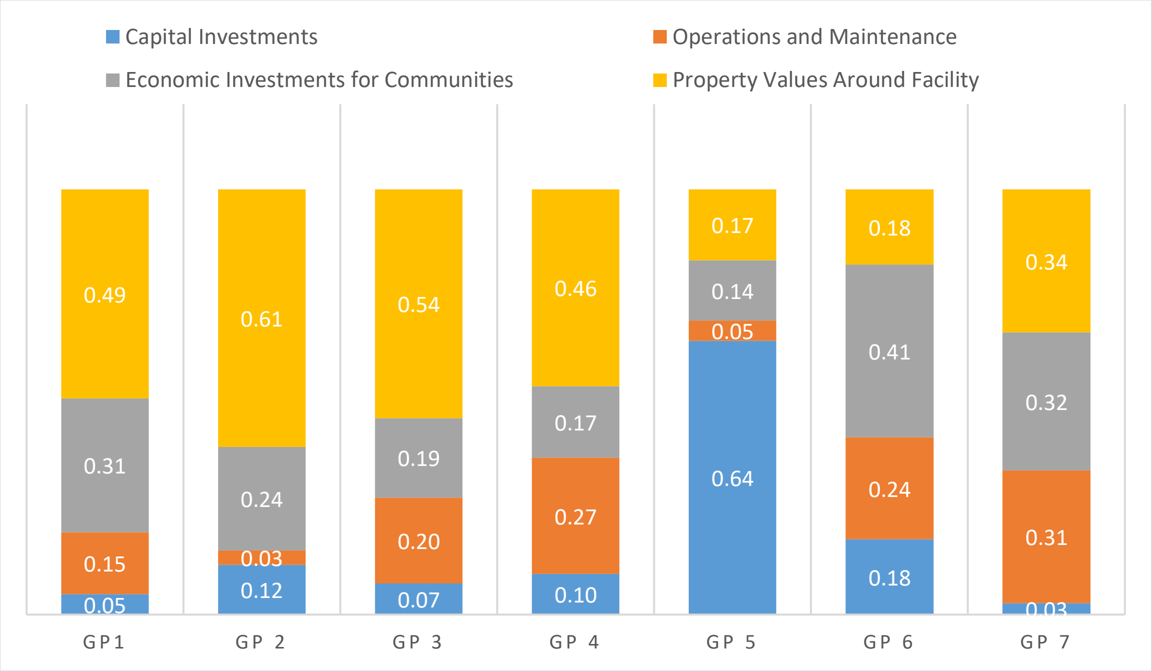

Figure 52: Part 2 Economics Attributes Prioritization for Group 3

Figure 53 presents the combined group priorities. When combined, the Group 1 priorities for the economic attributes are almost equal. This prioritization could be because SWA and CG stakeholders have to think about many aspects of MSW issues, in and out of their communities. And they have many stakeholders to answer to in their communities. Collectively the R stakeholders prioritize the operation and maintenance attribute the highest. Regulators are responsible for the protection of public health and the environment. They are required to inspect and monitor MSW facilities for the lifetime of the facility as well as when it is in post-closure care. Therefore, regulators would be concerned with the fact that a facility has the financial means to maintain and operate their facility per the regulatory requirements in the permit. The GP stakeholder prioritized property values around the facility. As discussed in the previous section, this makes sense, because the general public is concerned with issues directly affecting their community. When combined, the stakeholders have an almost equal preference for all attributes.

This could be difficult to use when trying to find the most important attribute to address in facility development.

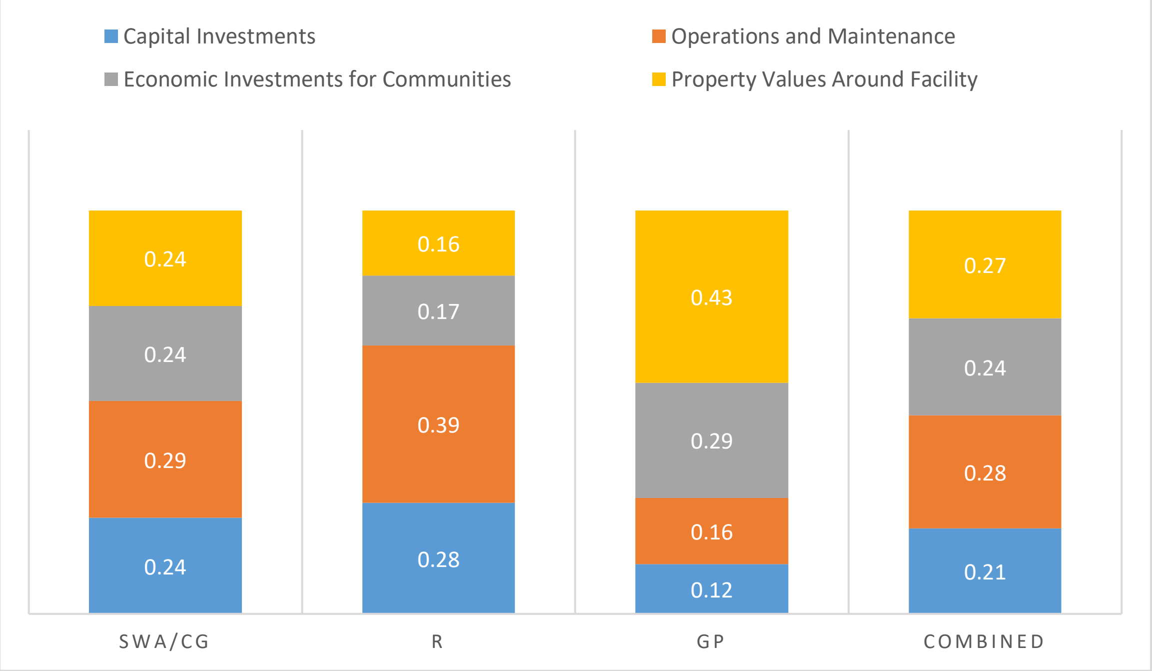

Figure 53: Part 2 Economics Attributes Prioritization for Combined Stakeholder Groups

Social Acceptance

Three attributes were evaluated and prioritized for the Social Acceptance criterion. Figure 54 presents the results from the Group 1 prioritization for social acceptance attributes. In four cases, the noise and odor attribute prioritized the highest (SWA 2, CG 1, CLM 1, and CLM 2). Often, operators of MSW facilities will receive complaints about the noise and odor of a facility. These aspects are often one of the most noticed by the surrounding community. The ease of removal and management attribute of MSW was prioritized the highest by the remaining stakeholders.

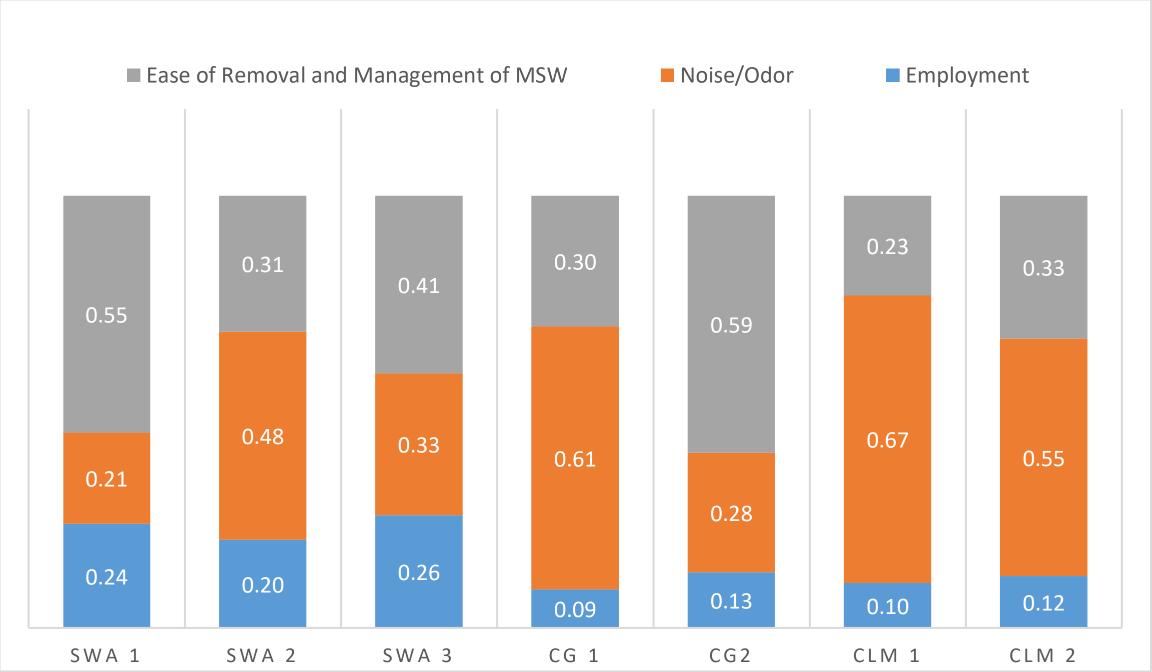

Figure 54: Part 2 Social Acceptance Attributes Prioritization for Group 1

Figure 55 presents the results from the Group 2 prioritization for social acceptance attributes. In five cases, the noise and odor attribute prioritized the highest. As with the Group 1 stakeholders, regulators often are the first to receive notification of noise and odor issues from the general public. These issues can sometimes be related to the operations of the facility. Often, operators of MSW facilities will receive complaints about the noise and odor of a facility. These aspects are often one of the most noticed issues in the surrounding community. The ease of removal and management of MSW was prioritized the highest by the remaining stakeholders.

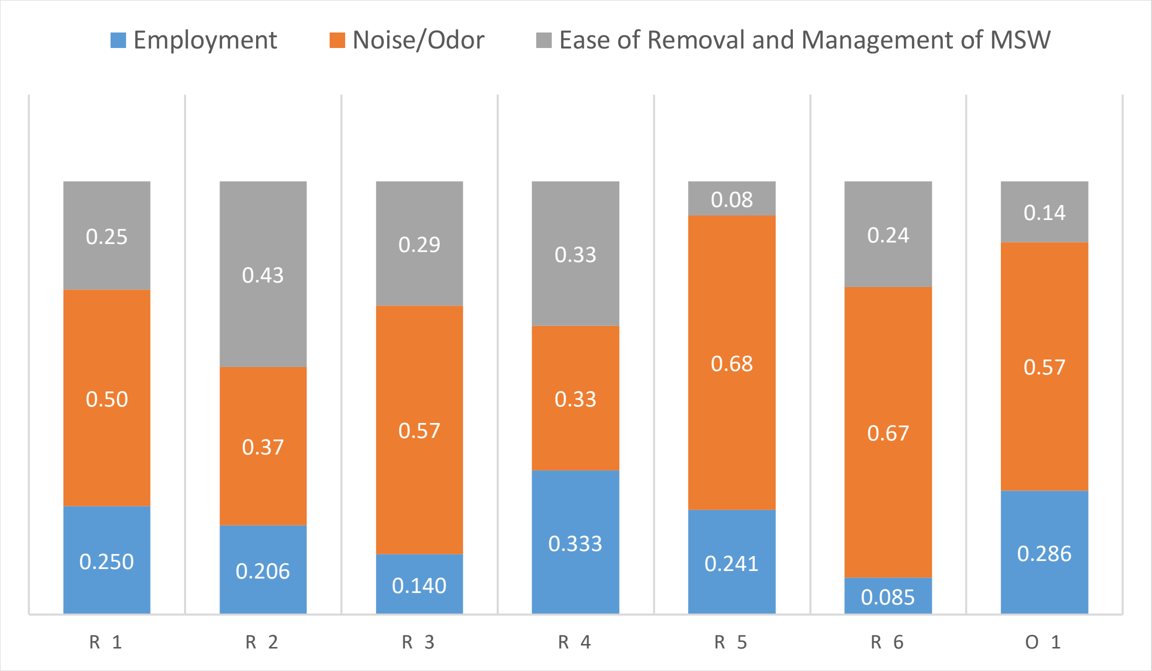

Figure 55: Part 2 Social Acceptance Attributes Prioritization for Group 2

Figure 56 presents the results from the Group 3 prioritization for social acceptance attributes. In four cases, the noise and odor attribute prioritized the highest. Noise and odor can affect the quality of life of those who are affected by a facility. These aspects are more tangible than the other attributes and have the potential to affect a larger group of people.

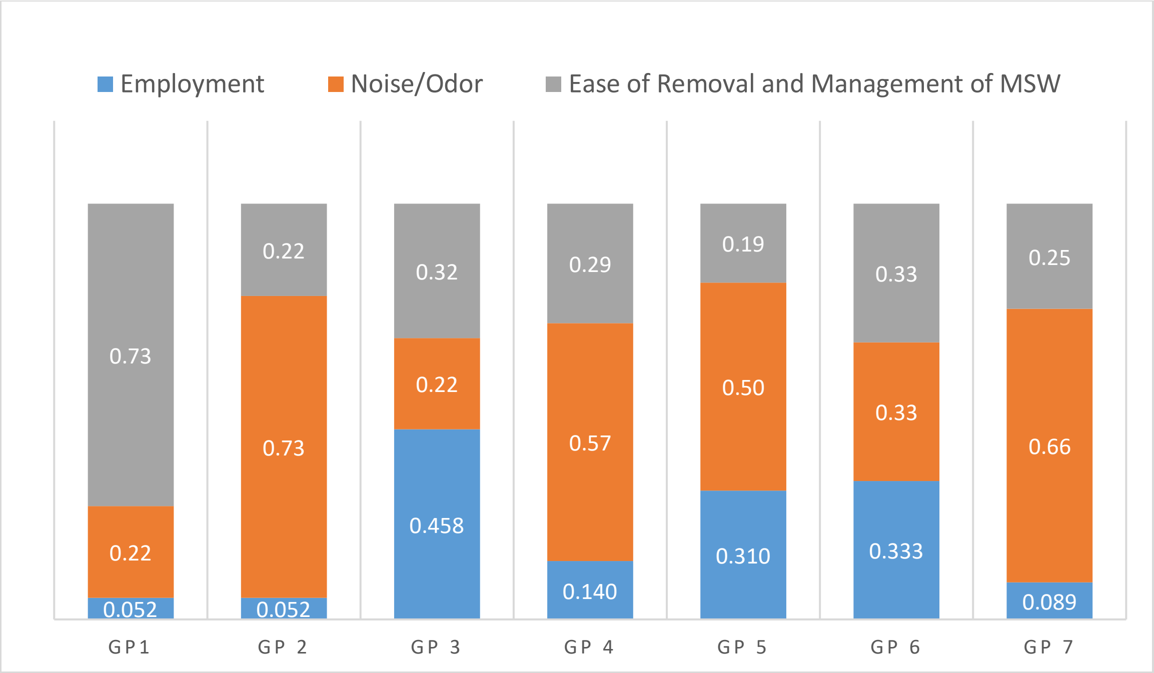

Figure 56: Part 2 Social Acceptance Attributes Prioritization for General Public Stakeholder Group

Figure 57 presents the combined group priorities. When combined, all three stakeholder groups, individually and combined, show that noise and odor is the highest prioritized attribute. This is a case where diverse stakeholder groups can come to a consensus on the attribute of most concern.

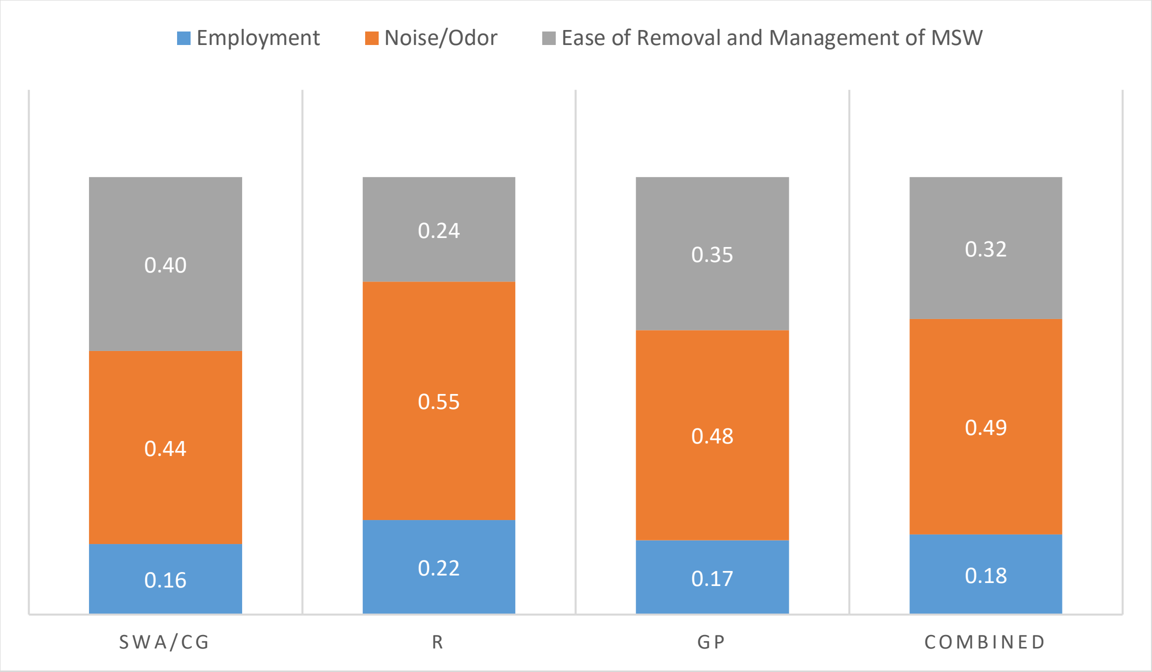

Figure 57: Part 2 Social Acceptance Attributes Prioritization for Combined Stakeholder Groups

Technical Feasibility

Five attributes were evaluated and prioritized for the Technical Feasibility criterion. Figure 58 presents the results from the Group 1 prioritization for technical feasibility attributes. This criterion has the greatest number of attributes, which may make it difficult for diverse stakeholders to find areas of agreement. Three stakeholders (SWA 1, SWA 2, and CLM 2) prioritized beneficial resource conservation as the highest priority, while three stakeholders (CG 1, CG 2, and CLM 1) prioritized distance from the community first.

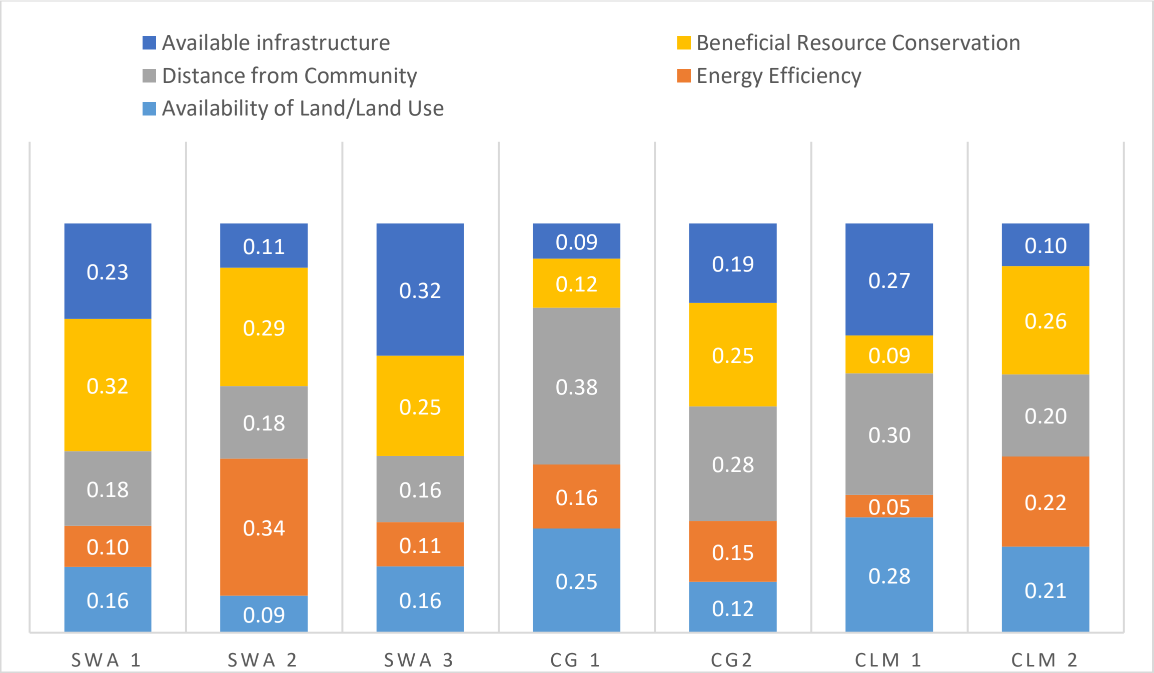

Figure 58: Part 2 Technical Feasibility Attributes Prioritization for Group 1

Figure 59 presents the results from the Group 2 prioritization for technical feasibility attributes. As with Group 1, there is not the primary attribute that was consistently prioritized over another. This criterion has the greatest number of attributes, which may make it difficult for diverse stakeholders to find areas of agreement.

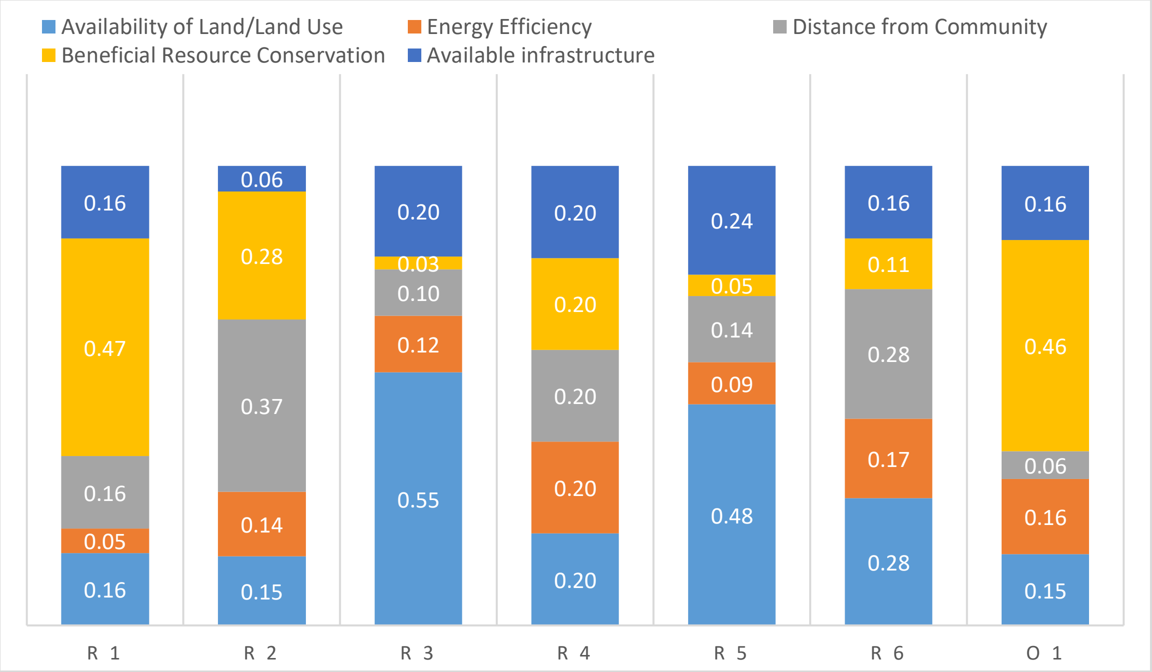

Figure 59: Part 2 Technical Feasibility Prioritization for Group 2

Figure 60 presents the results from the Group 2 prioritization for technical feasibility attributes. As with Group 1 and 2, there is not the primary attribute that was consistently prioritized over another. This criterion has the greatest number of attributes, which may make it difficult for diverse stakeholders to find areas of agreement.

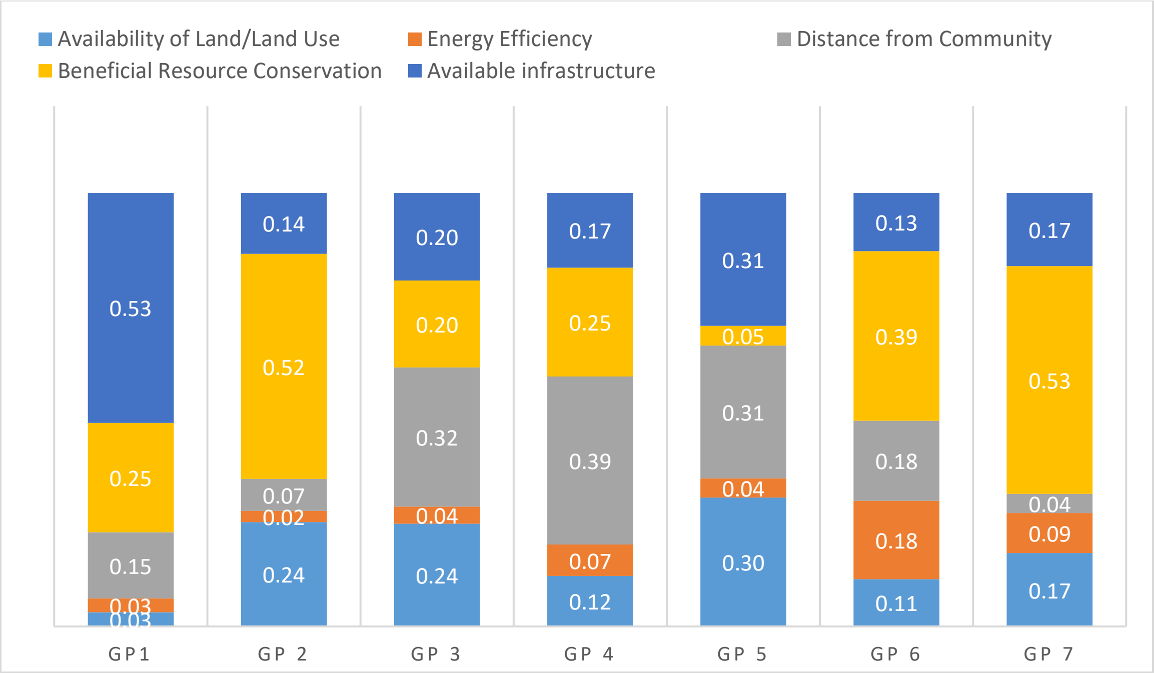

Figure 60: Part 2 Technical Feasibility Attributes Prioritization for Group 3

Figure 61 presents the results from the Group 2 prioritization for technical feasibility attributes. Though when all stakeholders are combined, it is difficult to select the top prioritized attribute. Energy efficiency is the least prioritized attribute. In the future, it may not be necessary to consider this attribute further.

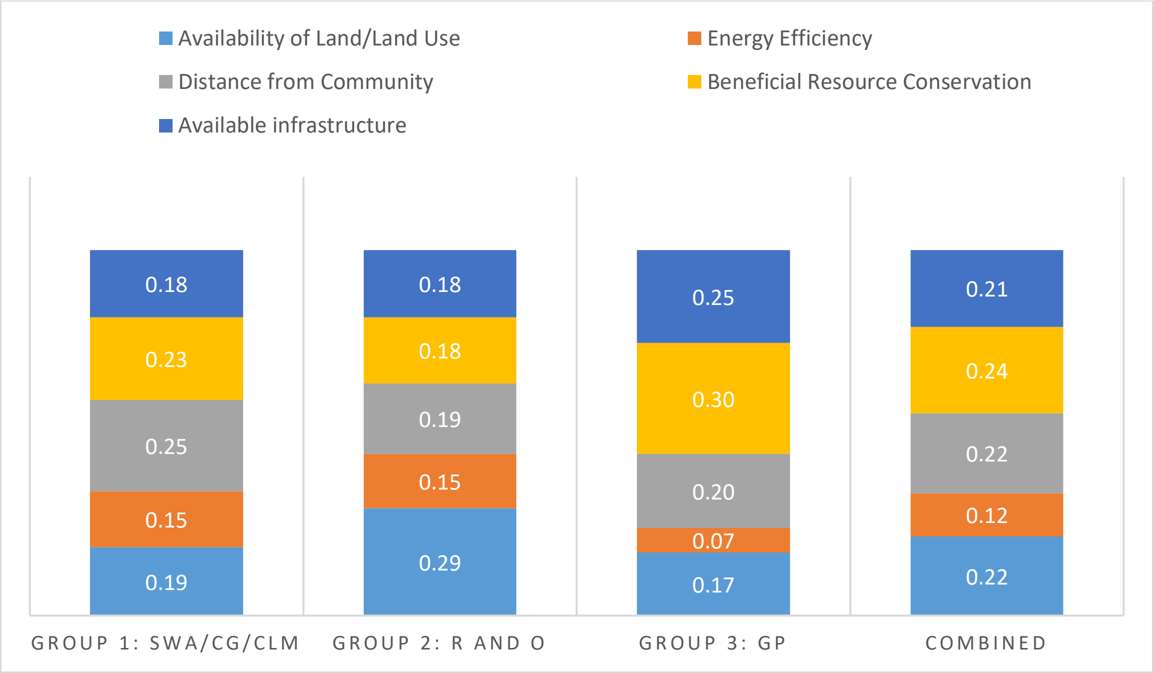

Figure 61: Part 2 Technical Feasibility Attributes Prioritization for Combined Stakeholder Groups

Regulatory Acceptance

Three attributes were evaluated and prioritized for the Regulatory Acceptance criterion. Figure 62 presents the results from the Group 1 prioritization for regulatory acceptance attributes. Three stakeholders (SWA 3, CLM 1, and CLM 2) prioritized applicable regulation as the highest priority. SWA 1 and CG 1 prioritized these attributes equally.

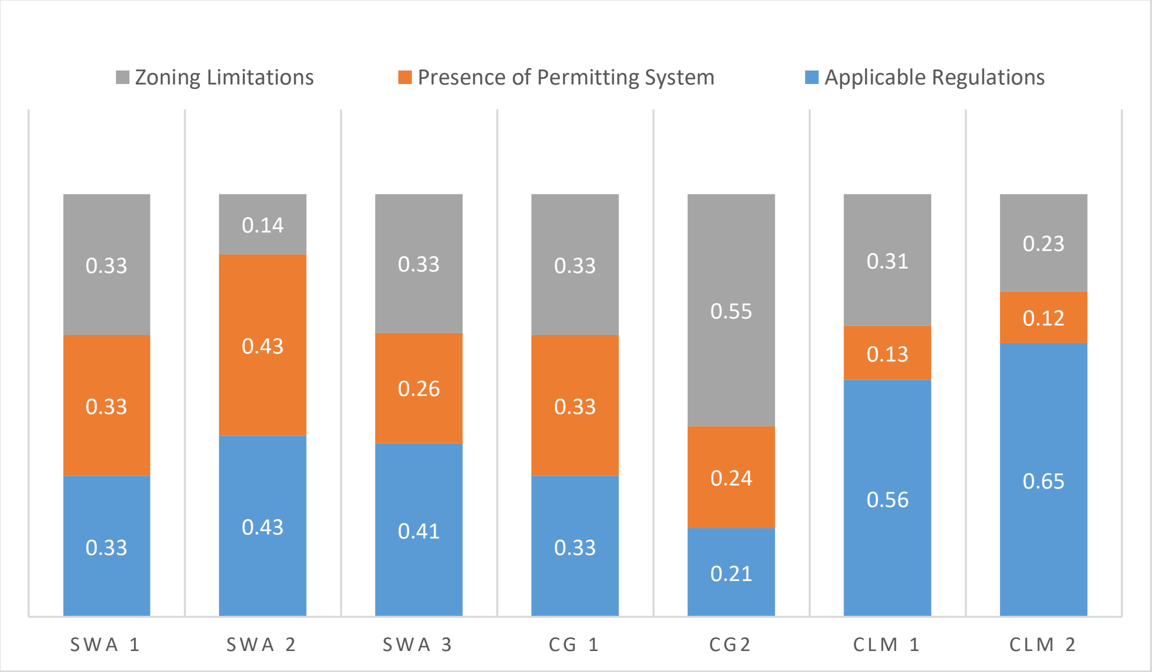

Figure 62: Part 2 Regulatory Acceptance Attributes Prioritization for Group 1

Figure 63 presents the results from the Group 2 prioritization for regulatory acceptance attributes. R 5 and R 6 prioritized zoning limitations as the highest priority. R 1, R 3, and R 4 prioritized these attributes equally.

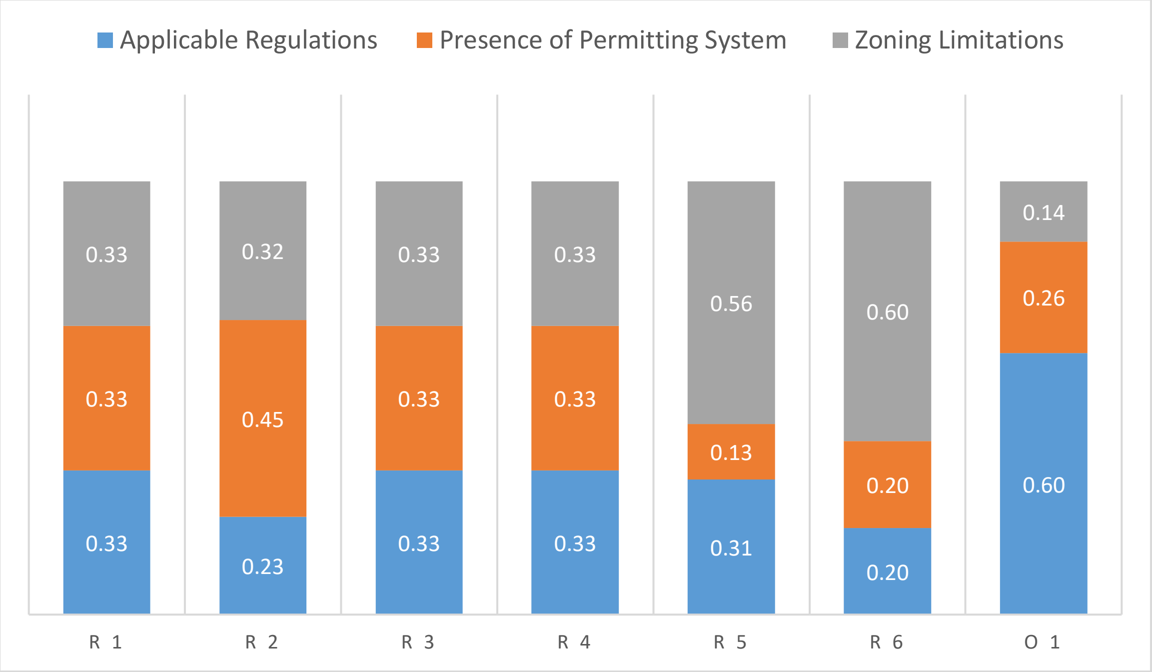

Figure 63: Part 2 Regulatory Acceptance Attributes Prioritization for Group 2

Figure 64 presents the results from the Group 2 prioritization for regulatory acceptance attributes. Five stakeholders (GP 1, GP 2, GP 3, GP 5, and GP 7) prioritized zoning limitations first. Zoning is often one of the ways a community must prevent the development of certain types of facilities. The public also has input to zoning uses changes.

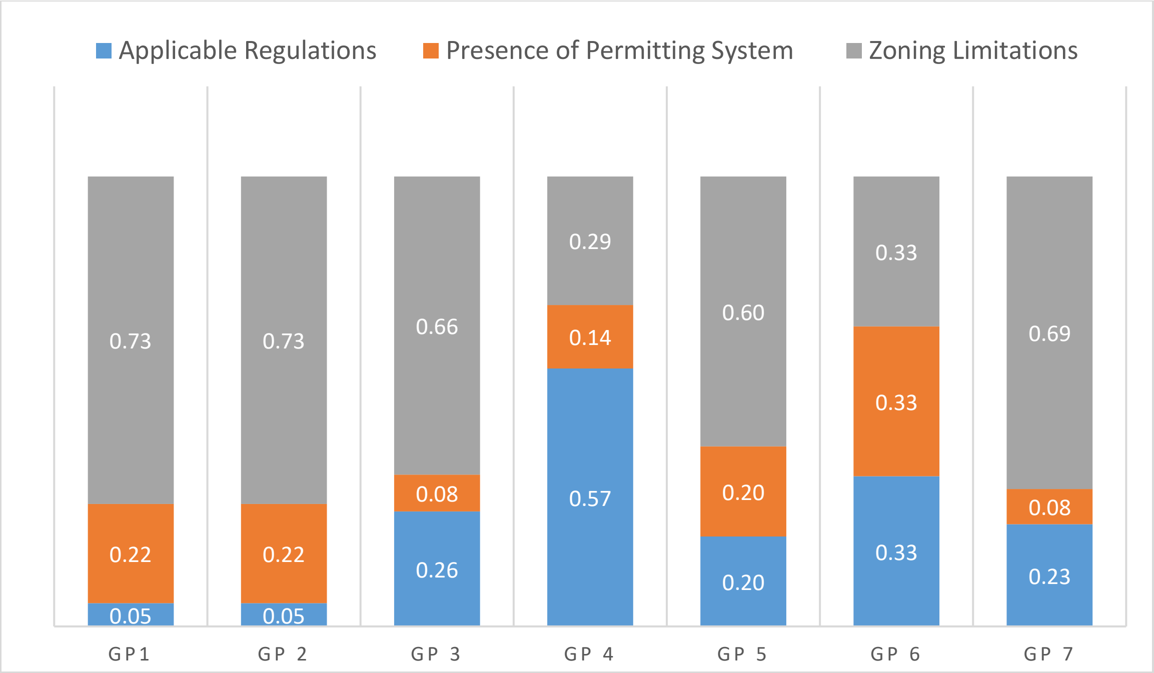

Figure 64: Part 2 Regulatory Acceptance Prioritization for Group 3

Figure 65 presents the results from the combine prioritizations for regulatory acceptance attributes. When combined, Groups 2 and 3 prioritize zoning limitations attribute first. When all three groups are combined, the zoning limitations attribute is also prioritized first.

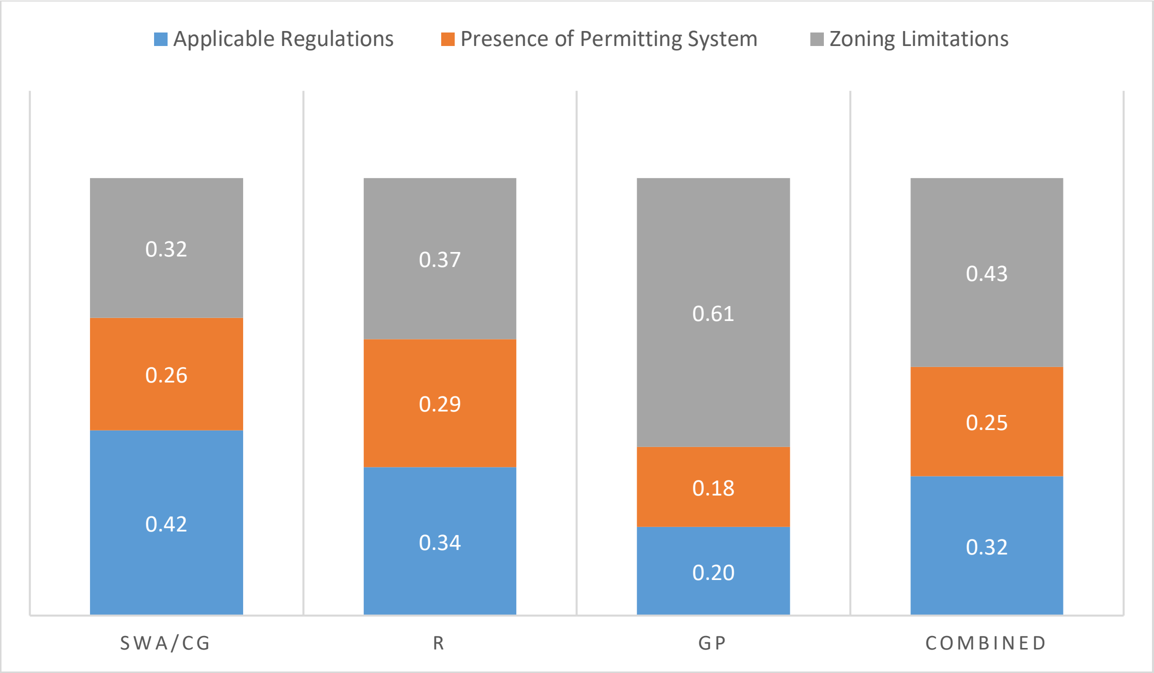

Figure 65: Part 2 Economics Attributes Prioritization for Combined Stakeholder Groups

Part 3: Scenario Evaluation

The results for Part 3 are broken into three sections for each scenario. Figure 66 shows the results. Each scenario was compared to the criteria from Part 1 with respect to the goal/objective. CG 1 and CG 2 prioritized the scenarios in the same order, with Scenario 2: Waste to Energy first. CLM 1 was the only stakeholder to prioritize Scenario 1 first, which might be due to the role the stakeholder plays in his or her position as a cooperated landfill manager.

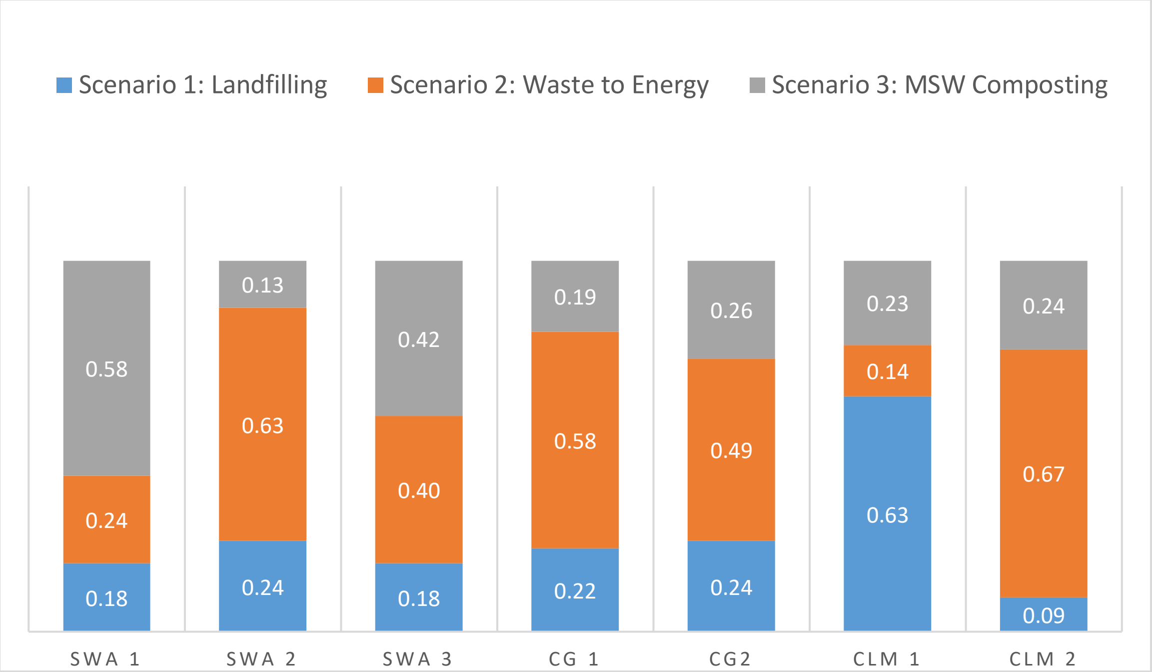

Figure 66: Part 3 Combined Scenario Prioritization for Group 1

The results for Group 2 are shown in Figure 67. Landfilling was prioritized first by R 4. R 3, R 5, and O 1 prioritized Scenario 2: waste to energy first, while R 1, R 2, and R 6 prioritized Scenario 3: MSW composting first. This result shows, as with Group 1, that there is a lack of consensus on how these scenarios will best meet the objectives and criteria.

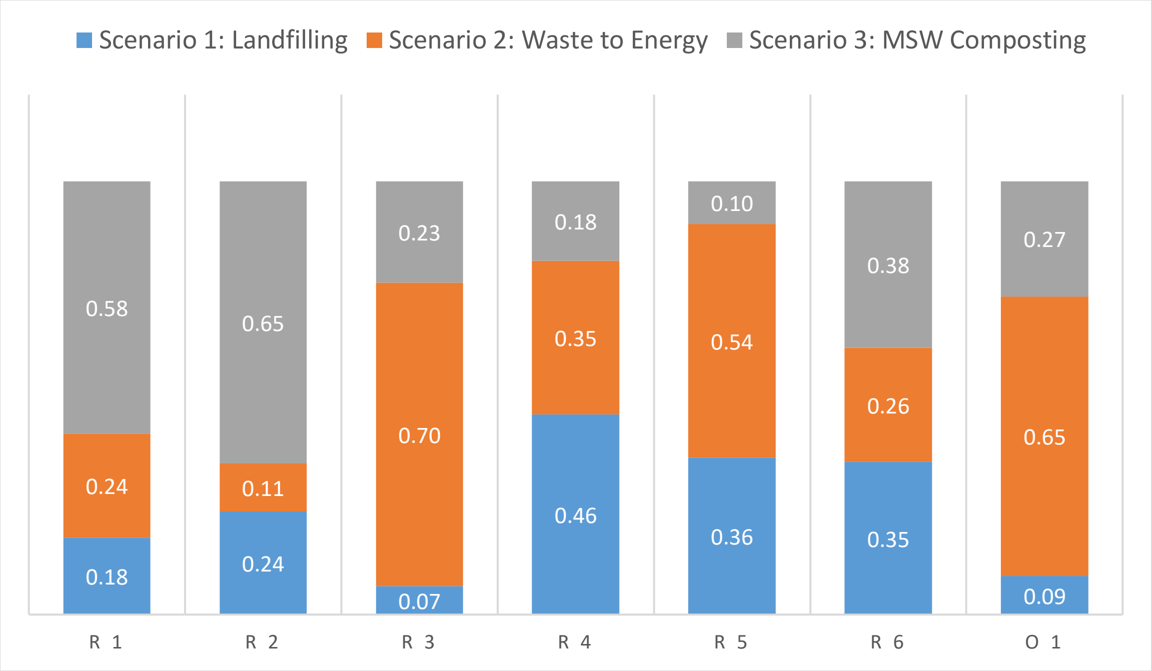

Figure 67: Part 3 Combined Scenario Prioritization for Group 2

The results for Group 3 are shown in Figure 68. Landfilling was prioritized the lowest of all scenarios by all the stakeholders in this group. This result fits the general public opinion of landfills and their negative effects. GP 3, GP 6, and GP 7 had about equal prioritization for Scenarios 2 and 3. GP 1 prioritized Scenario 3: MSW composting much higher than Scenario 2: waste to energy and GP 2 prioritized Scenario 2: waste to energy over Scenario 3: MSW composting. As with the other stakeholder groups, there is no one scenario that can be seen as the preference of the group.

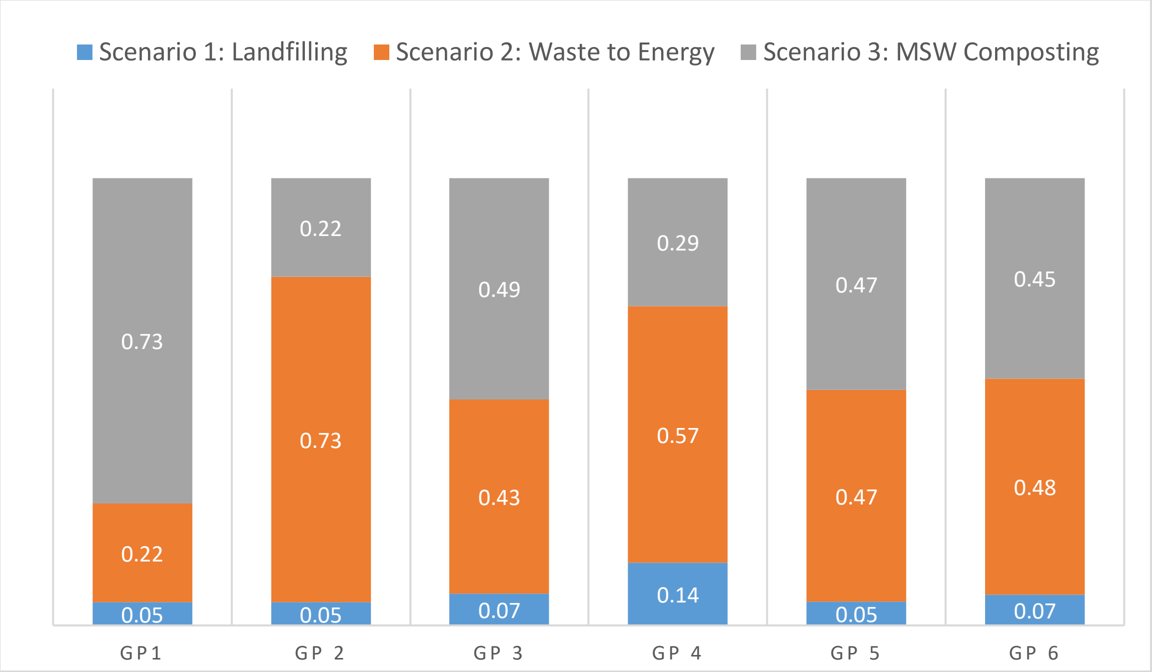

Figure 68: Part 3 Combined Scenario Prioritization for Group 3

Figure 69 presents the combined prioritization for each stakeholder group as well as the prioritization of all the stakeholders combined. All three stakeholder groups prioritize Scenario 2: waste to energy over the other scenarios. Therefore, when combined, Scenario 2: waste to energy is the preferred scenario to meet the goal/objective of the elicitation.

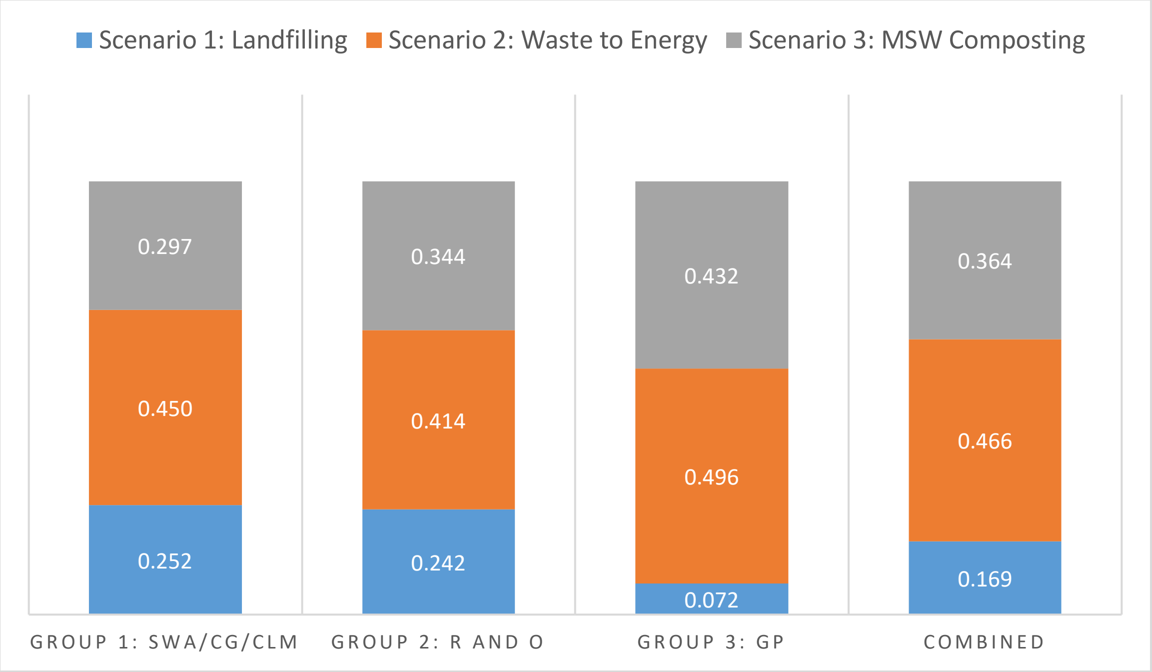

Figure 69: Part 3 Scenario Combined Group Priority Results

Consistency

The CI and CR were calculated for each stakeholder. As discussed in Chapter III, if the stakeholder's pairwise comparisons fail the consistency check, then it is concluded that the stakeholder has been illogical or has made a mistake in the pairwise comparisons process. The CR value is calculated by dividing CR values by the random index value. The random index value is intended to account for natural human inconsistency when answering the pairwise comparison. When CR values are greater than 0.1 or 10 percent, the stakeholders' judgments are considered to be inconsistent. Though some AHP practitioners argue that a consistency greater than 0.2 or 20 percent is considered to be inconsistent, instead of 0.1 or 10 percent. One CI and one CR value are calculated for pairwise comparison. For example, for Part 1, there is only one CI and CR. In all, eleven CI and CR values were calculated. The CI values for all participants are shown in Figure 70. Figure 71 presents the CR values with a yellow dotted line representing the 0.1 and a red dotted line representing the 0.2 consistency line. In both graphs, green represents Group 1 (SWA/CG/CLM), red represents Group 2 (R/O), and blue represents Group 3 (GP).

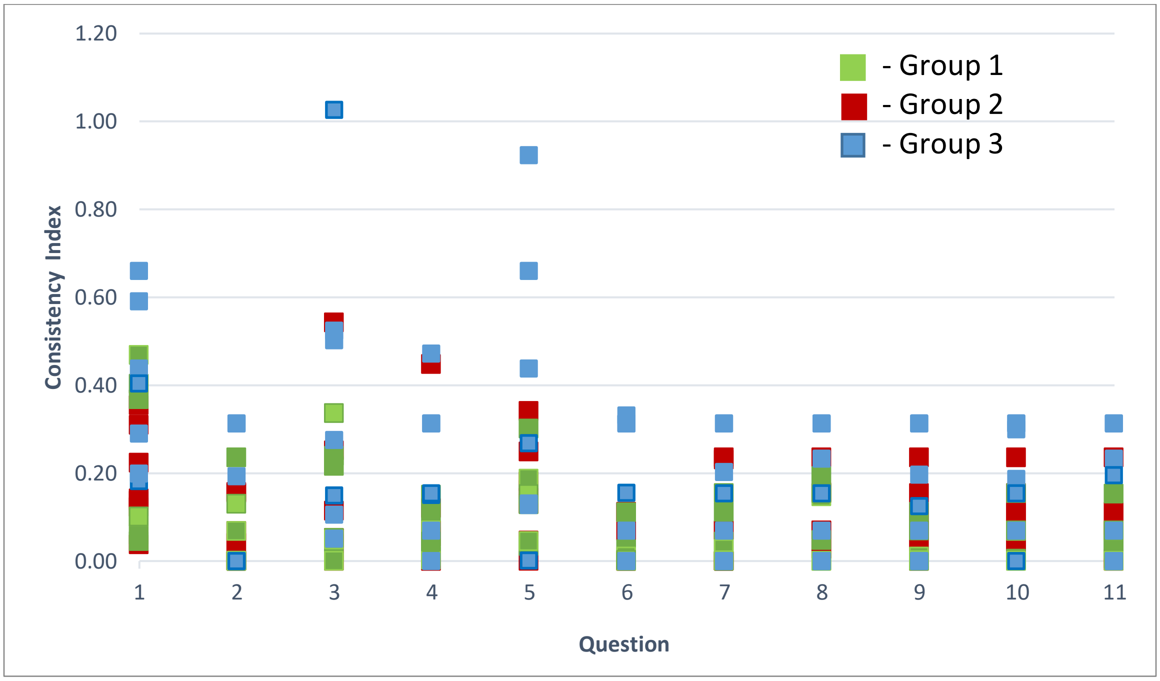

Figure 70: Consistency Index Results for All Stakeholders

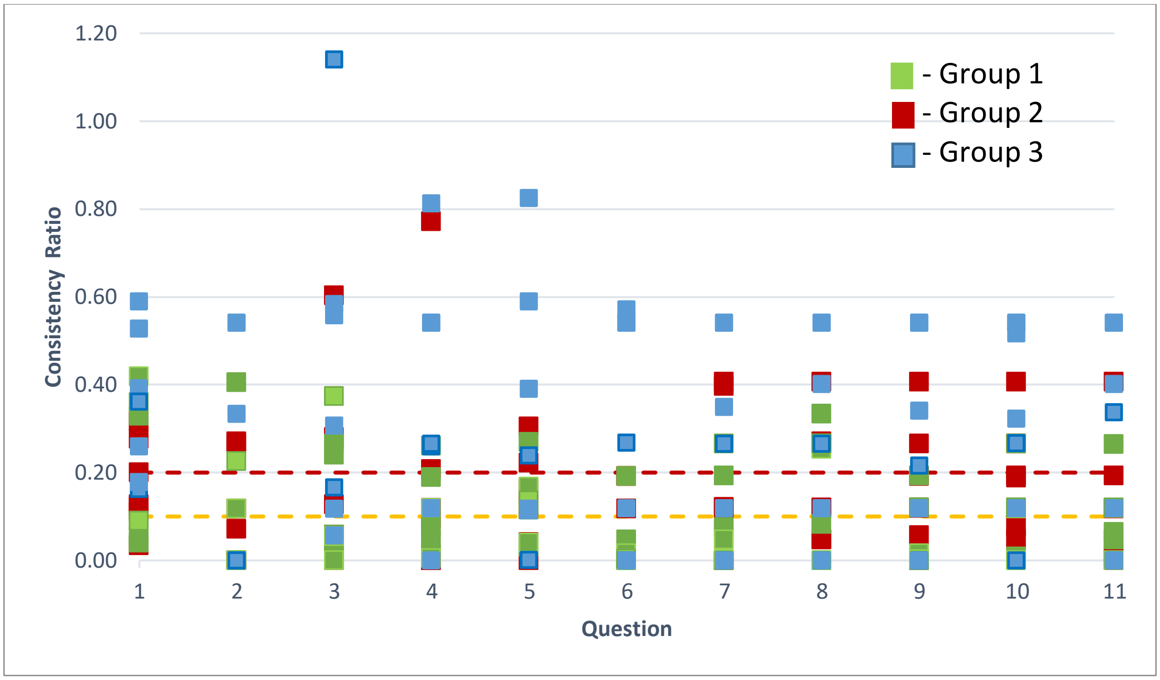

Figure 71: Consistency Ratio Results for All Stakeholders

Based on a review of the CR values in Figure 71, it appears that the majority of the stakeholders have CR values above 0.1 and 0.2. Based on this, the majority of the stakeholders are considered inconsistent, and their judgments should not be carried forward. Yet, some stakeholders were considered inconsistent on some CRs and consistent on others. To observe the trends of the stakeholders and their CRs., the CRs were graphed using a trend line. The 0.1 value is graphed as a red dashed line, and the 0.2 value is graphed as a blue dashed line. Stakeholders who had the majority of their CR values less than 0.1 are colored in a shade of red. Stakeholders who had the majority of their CR values less than 0.2 are colored in shares of blue. The remaining values are graphed in shades of grey.

Figure 72 shows the graphed CR results for Group 1. The most consistent stakeholders were SWA 1, SWA 3, and CG 2. SWA 2 and CG 1 had CR values below the 0.2 line. CLM 1 and CLM 2 had most of the CR values about the 0.2 line.

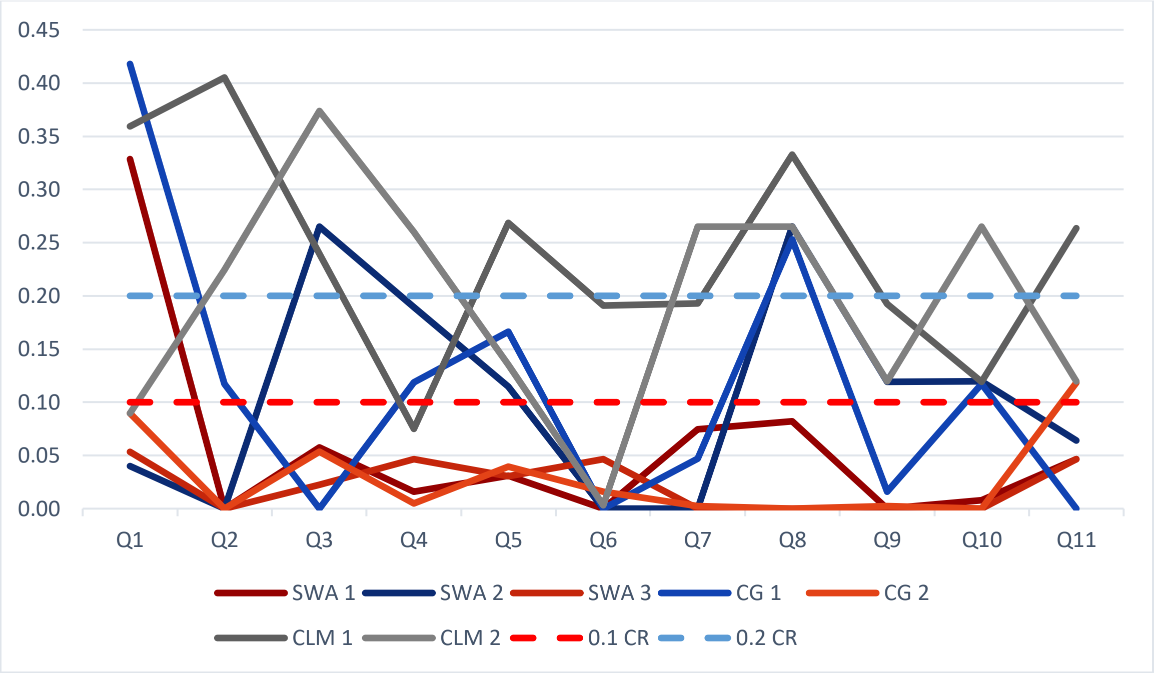

Figure 72: Consistency Ratio Results for Group 1: SWA, CG, and CLM Stakeholders

Figure 73 shows the CR values for Group 2. Only stakeholder R1 had CR values mostly under 0.1. Stakeholders R 2, R 4, and R 6 had the majority of their values under 0.2. Stakeholder R 3, R5, and O1 had CR values above 0.2 and considered inconsistent.

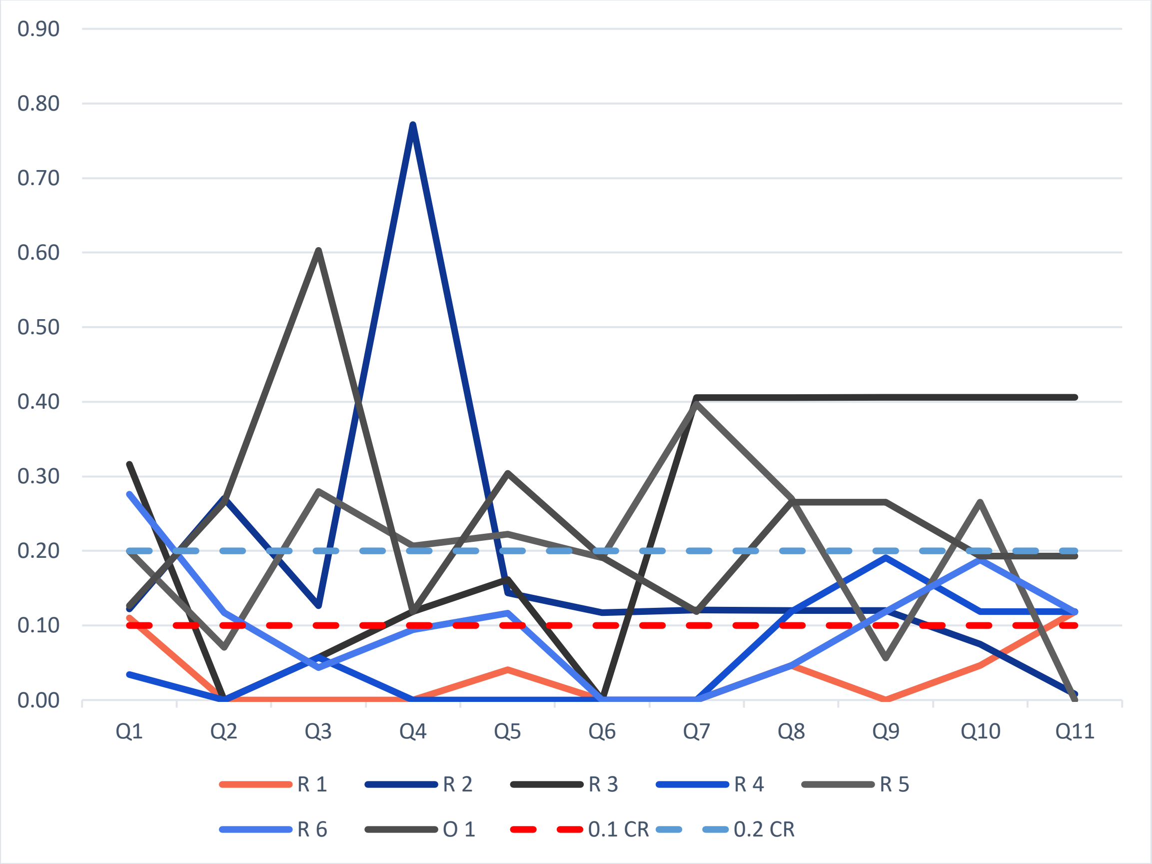

Figure 73: Consistency Ratio Results for Group 2: R and O Stakeholders

Figure 74 shows the CR values for Group 3. No GP stakeholders had the majority of their CR values under 0.1. GP 4, GP 5, and GP 6 had the majority of the CR values under 0.2. GP 1, GP 2, GP 3, and GP 7 had the majority of their consistency values above 0.2.

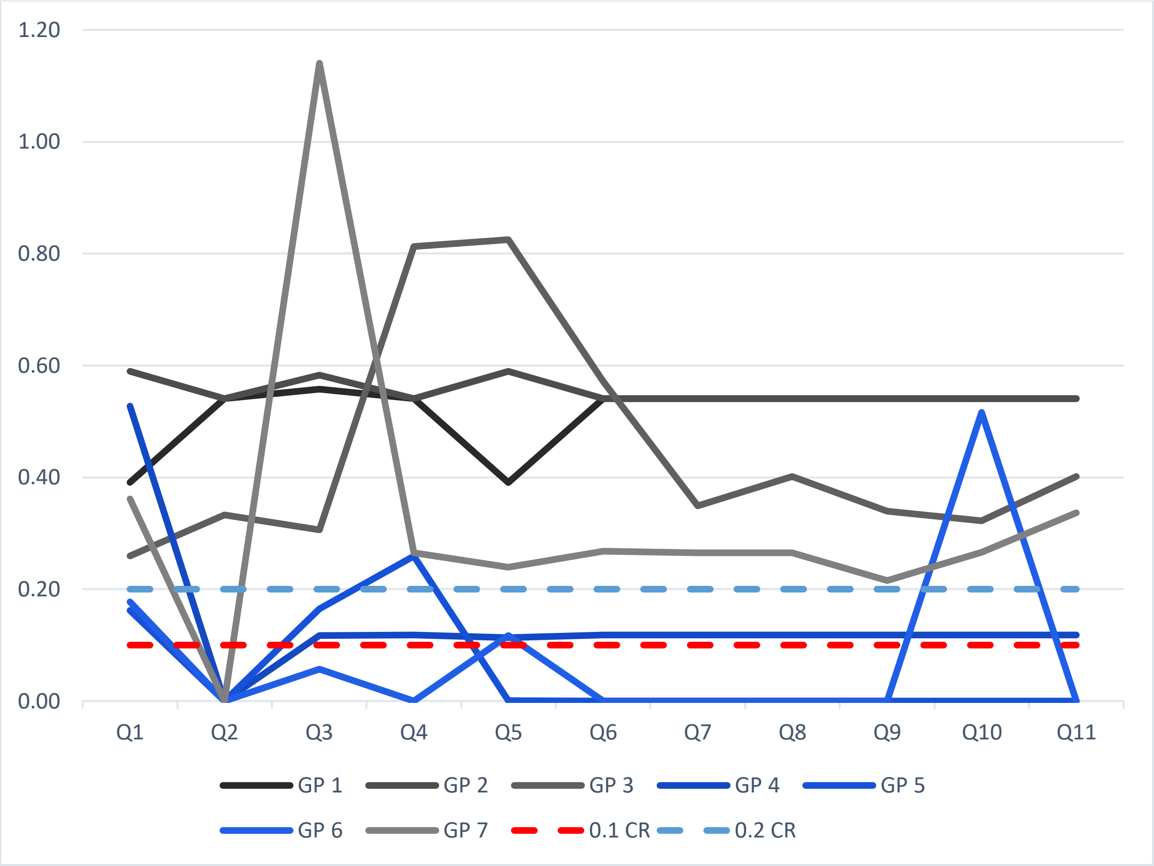

Figure 74: Consistency Ratio Results for GP Stakeholders

Control Chart Evaluation

Since there was a high number of inconsistent stakeholder responses, additional consideration was made to determine if there are other ways to evaluate consistency. Since the goal of DecisionTogether© is to allow for inclusive group decision-making, it would be very difficult to have final individual and group priorities if all the stakeholders were excluded from the elicitation. The elicitation CR values are evaluated to determine if some stakeholders were fairly consistent in their responses, even if their CR values were greater than 0.1 and 0.2.

As stated previously, when the standard consistency tests yield a CR value above 0.1, the recommendation from AHP practitioners is to ask stakeholders to revisit their responses to their pairwise comparison. Karapetrovic and Rosenbloom (1999) found in their research that when stakeholders are asked to revisit their responses, there is not much of a change in the CI/CR. Often the stakeholder did not make a mistake in the pairwise comparison as they are quite conscientious in their evaluation during an AHP elicitation. The stakeholders rarely make random pairwise comparisons, even if they fail the consistency test (Karapetrovic & Rosenbloom, 1999).

Karapetrovic and Rosenbloom (1999) proposed a quality control approach to consistency tests to evaluate the results of stakeholder pairwise comparisons, which fail the standard consistency test. Rather than looking at one pairwise comparison matrix at a time for consistency, they propose a control chart method that monitors and controls the consistency of an entire decision-makers process. Instead of calculating CR, it is proposed that all the CIs calculated during the elicitation are plotted on a moving average control chart using consistency indices as individual observations of consistency. Once a control chart is plotted, they can be evaluated for any special causes in the variation of the inconsistency of particular stakeholders. These special causes may be indicated on the charts as points outside control limits, upward and downward trends, or a large number of consecutive points above or below the central line (Karapetrovic & Rosenbloom, 1999).

Control charts consist of graphing the moving average of a set of CI values for a stakeholder. The standard deviation is calculated for the stakeholder. Lines for three times the upper and lower standard deviation are also graphed on the control chart. The moving average is reviewed to see what trends can be observed (upward and downward) and if the moving average stays within the upper and lower standard deviation lines. A point that is outside three standard deviations is considered an out-of-control situation. It may indicate that a stakeholder was inconsistent with their judgments of a particular set of criteria, attributes, or alternatives. It could also indicate the stakeholder made an error in their judgment. Non-mutually preferentially independent (MPI) attributes or unclear distinction between alternative may contribute to this occurrence. Other special causes of variations may be indicated by upward or downward trends, or a string of points above or below the central line (Karapetrovic & Rosenbloom, 1999).

For the evaluation of a stakeholder, a single point outside of control limits could indicate a chance rather than a special cause of variation. The data evaluator must carefully examine possible special causes after the control chart has been plotted. This examination should also include the choice of the control chart and the type of subgrouping (Karapetrovic).

When looking at the control charts, variation within a sample is evaluated. For moving average charts, a point above the control limit might indicate that one or more stakeholders made a mistake. If the corresponding point on the graph is within the standard deviation limits, then it may be that the stakeholder is at fault. But, if the corresponding point on the graph is above the upper standard deviation, this could indicate that the constructed hierarchy is erroneous in some way, and the stakeholders are having a problem with the particular matrix. An upward trend may indicate fatigue of a stakeholder in completing the pairwise comparisons. A downward trend may indicate that the stakeholder is trying harder to be consistent as the process continues. If the decision-maker is unfamiliar with the pairwise comparison process, he/she may have early judgments outside the control limits. Some decision-makers may be able to correct their ability to make consistent judgments. The results may be mostly below the central line on the moving average control chart and an erratic pattern on the moving range chart. The moving range control chart looks for variations within samples. As with moving average control charts, a point outside the control limits may indicate that the decision-maker made a mistake (Karapetrovic).

The process to prepare the control charts are as follows:

1. Each stakeholder provides his or her input into the series of pairwise comparison matrices for the hierarchy. The CI is calculated for each matrix. For this research, there are 11 matrices, one for Part 1, criteria evaluation, five for Part 2, attribute evaluation, and five for Part 3, alternatives evaluation.
2. Calculate the CI moving average, associated standard deviation, and average based on the CI results.
3. Create graphs for each stakeholder with the moving average, standard deviation, and average.
4. Analyze each participants' graphs to determine if the stakeholder and their evaluation are out-of-control or not. If the process is out of control, a determination needs to be made about why the process is out-of-control. If necessary, some of the pairwise comparisons may be reevaluated. If not, the process is in control, and the AHP evaluation can proceed.

Based on a review of Figure 72, Figure 73, and Figure 74, a stakeholder with the majority of their CR values below the blue and red dashed lines (blue and red lined data) was retained for evaluation using the moving average. In a review of the CR values, many participants seem to have provided inconsistent answers to their pairwise comparisons. In some cases, participants made pairwise comparisons that were consistent for some sections and inconsistent for others. To further evaluate constancy, control charts were graphed selected stakeholders. Stakeholders with a majority of the CR values below 0.2 were evaluated using the control charts. The stakeholders kept for further consideration are in Table 28.

Table 28: Stakeholders Sorted by Consistency Ratios

Majority of CRs Less Than 0.1	Majority of CRs Less Than 0.2	Majority of CRs Greater Than 0.2
SWA 1	SWA 2	CLM 1
SWA 3	CG 1	CLM 2
CG 2	R 2	R 3
R 1	R 4	R 5
	R 6	O 1
	GP 4	GP 1
	GP 5	GP 2
	GP 6	GP 3
		GP 7

The control charts for the stakeholders in the first and second columns were evaluated, as shown in Appendix F.

Control Chart Example

Control charts were created for the stakeholders in columns one and two of Table 28. To show the method used in the control chart analysis, stakeholders SWA 1 and SWA 2 were evaluated.

Control charts were created for the moving average and upper and lower limits (three times the standard deviation of the averages) for the stakeholder. The moving average control chart was graphed for stakeholder SWA 1 (Figure 75). The moving average of CI stayed within the standard deviation and near the CI Average. Though there was a high inconsistency in Part 1, SWA 1 improved the CR values during the rest of the elicitation process. It appears that the stakeholder became more comfortable with the process and was able to achieve more consistency in the pairwise comparisons for Parts 2 and 3. Based on a review of the CR values and the control chart, SWA 1’s results should be retained to calculate stakeholder group consensus.

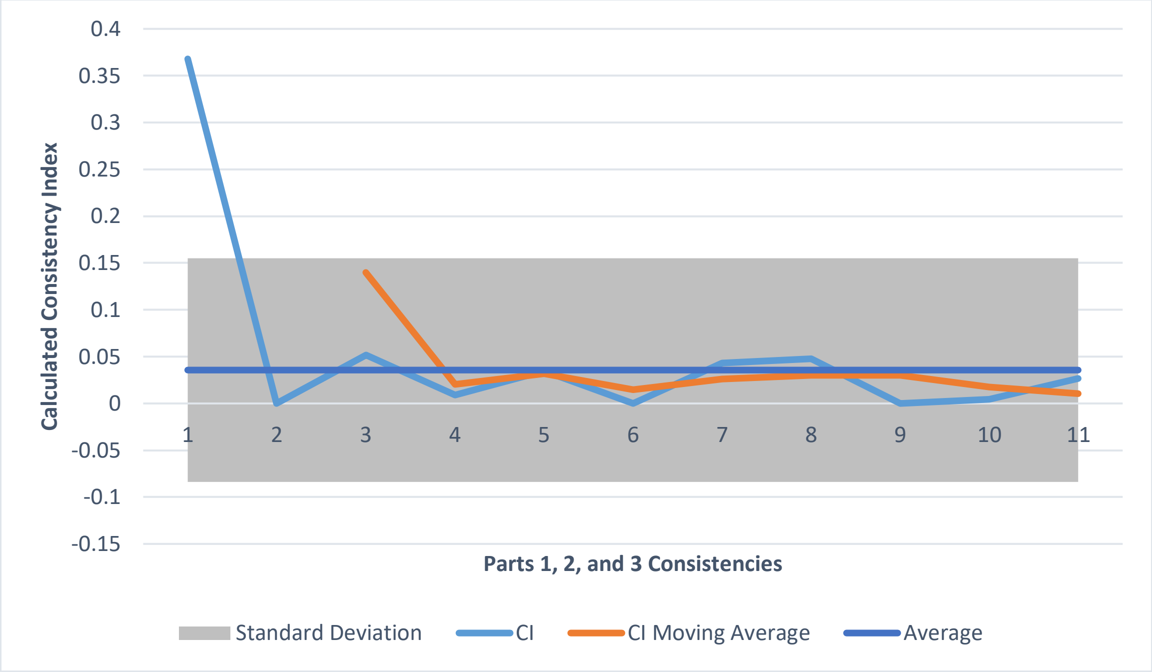

Figure 75: SWA 1 Moving Average Control Chart.

The moving average control chart was graphed for stakeholder SWA 2 (Figure 76). The moving average of CI stayed within the standard deviation and is erratic. It appears that the stakeholder was not able to maintain a steady CI. Also, this stakeholder had most of their CR values above the 0.1 CR limit. Based on the review of the CR values and the control chart, SWA 2's results will not be retained to calculate stakeholder group consensus.

Figure 76: SWA 2 Moving Average Control Chart

The reaming evaluated control charts are located in Appendix F. Stakeholders SW1, SW 3, CG 1, CG2, R 1, R 2, GP 4, and GP 5 are retained for further evaluation of group priorities.

Adjusted Prioritization Based on Consistency

The prioritizations were graphed for the retained stakeholders. Group 1 consists of SW 1, SW 3, CG 1, and CG 2. Group 2 consists of R1 and R2. Group 3 consists of GP 4 and GP5. The goal of this section is to evaluate how the removal of stakeholders who are considered inconsistent changes the overall prioritization.

Part 1

The group and total priorities are presented in Figure 77 for the original and adjusted comparisons. The adjusted comparisons included only eight of the original 21 stakeholders.

Group 1 consists of four stakeholders, and Groups 2 and 3 consists of two. In the case of Group 1, the prioritization of the criteria stayed relatively the same. But in the case of Groups 2 and 3, there is a drastic difference in prioritization. If the inconsistent stakeholders are removed, then there is the potential for a much different outcome, though the adjusted outcome may be more in line with those stakeholders who understood the AHP process, the criteria, attributes, and scenarios being evaluated, in order to provide better consistency. When the three groups are combined, the first prioritized criterion is still technical feasibility. The value for regulatory acceptance reduced, which can be seen across all combined stakeholder groups.

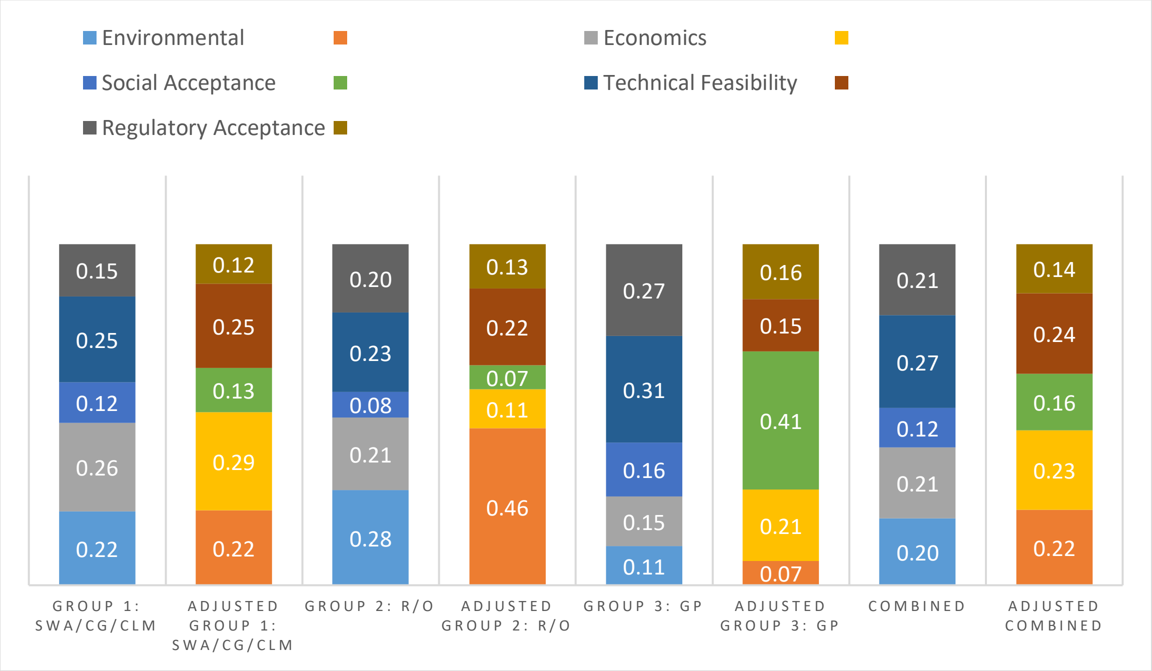

Figure 77: Part 1 Group Prioritization Adjusted for Consistency

Part 3

The original and adjusted prioritization for the scenarios is shown in Figure 78. As with Part 1, the adjusted prioritization for Group 1 stayed similar to the original. Group 3 shows the same prioritization order for the scenarios, unlike Part 1. Group 2 has a very different prioritization, with Scenario 3 being prioritized first for al Group 2 stakeholders, but Scenario 3 is the most preferred. This graph shows that the removed stakeholder had a different prioritization of the scenarios with respect to the criteria then the remaining stakeholders.

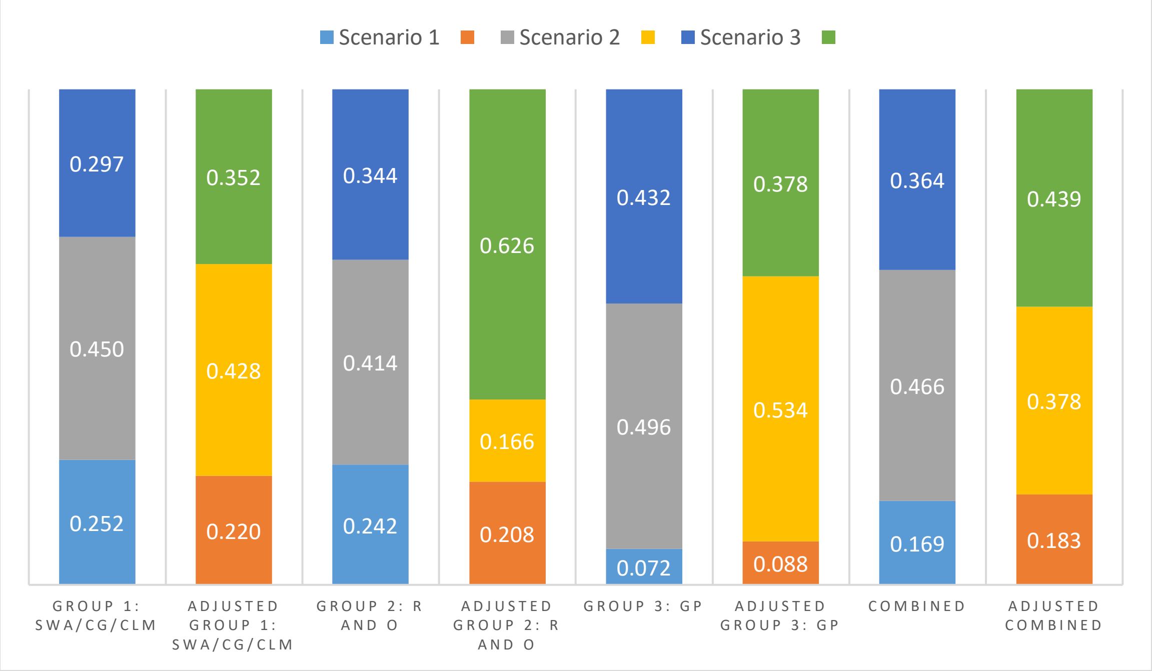

Figure 78: Part 3 Group Prioritization Adjusted for Consistency

Comments from DecisionTogether© Stakeholders

The review of the adjusted prioritizations shows that the removal of stakeholders considered to be inconsistent can have a dramatic change in the outcome of the prioritizations for Part 1 and Part 3. As discussed previously, the intent of the AHP process is not to create robotic responses from stakeholders to achieve a CR valued of below 0.1 or 0.2. Since the elicitation was based on a hypothetical case, there was limited quantitative data available for review by stakeholders. Also, some of the criteria and attributes are qualitative in nature and rely on the stakeholder to make the judgment of preference as well as the magnitude of that judgment.

To better understand the perspective of the stakeholders in the elicitation process, the stakeholders were contacted and asked to complete a short survey on their prioritization results for Part 1 (Criteria) and Part 3 (Scenarios). The purpose of this interview was to evaluate if the priorities calculated are in line with the stakeholder's perspective of prioritization. In addition, it allowed for the consideration of how consistency and results could be compared. Based on the previous discussion, AHP states that a stakeholder with a consistent ratio greater than 0.1 should be considered inconsistent and should not be included in the future evaluation of group priorities. In some cases, stakeholders are asked to return to their pairwise comparison to modify their answers to allow for a more consistent response. Yet, this action could have an impact on a stakeholder's answers, and in order to be more consistent, they may have to change their evaluations to fit, thus no providing their personal preferences to the evaluation. Based on a review of the results, no stakeholder had all their consistency ratios below 0.1. Based on a review of the control charts in the previous section, only eight of 21 stakeholders were considered consistent enough for continued consideration.

An important aspect of DecisionTogether© is that a diverse set of stakeholders should be engaged to evaluate environmental problems. If stakeholders are excluded, then the results are not representative of the group. DecisionTogether© intention is to provide an inclusive means to assess environmental problems. All stakeholders were asked to participate in the questionnaire based on their personal prioritization. Of the 21 stakeholders, eight stakeholders provided responses to the questions. The stakeholders were asked to review the pie chart results for Parts 1 and 3 and answer the following questions:

1. Do you feel that the priorities presented in the pie charts best represent your preferences and how you think/feel about the criteria, attributes, and alternatives for assessment future municipal solid waste systems?
2. What factors shaped the answers you provide in the elicitation?
3. What challenges and benefits do you see to these choices?
4. What do you think it would take to convince others of your prioritization?

The list of stakeholders who participated in the questionnaire is presented in Table 29 and . The comments provided by stakeholders are presented in Appendix G. Stakeholders from all three groups participated in the questionnaire. Though the majority of the stakeholders were not retained based on the CR value and/or the control chart evaluation, all respondents felt that the prioritizations presented to them were consistent with what they anticipated seeing based on their inputs.

Table 29: Stakeholder Who Participated in the Post Elicitation Questionnaire

Stakeholder ID	Retained Based on CR Value Control Chart Review	Felt Prioritizations Were Correct
CG 1	Yes	Yes
CG 2	Yes	Yes
R 2	Yes	Yes
R 5	No	Yes
R 6	No	Yes
GP 3	No	Yes
GP 6	No	Yes
GP 7	No	Yes

The themes from the comments provided by the stakeholders include:

1. Elicitation process:

    a. Allowing the stakeholder to see all the elements together provides a better understanding of the evaluation of criteria and alternatives
    b. Visual representation is helpful
    c. Doing the elicitation in a real-time public setting would help the process
    d. Educate the stakeholders and provide more information on criteria, attributes, and alternatives in order to participate in the elicitation process better.
2. Waste
    a. Waste needs to be diverted or minimized
    b. Waste is inevitable
    c. Organics management is important
3. Regulatory Framework
    a. There is a regulatory framework to help with technological development and still protect the environment

4. Social
    a. People do not want to pay for waste and waste issues
5. Environmental
    a. There is an environmental responsibility that we have to the future
6. Technologies
    a. The general public is not a big fan of landfills
    b. Scaling is an issue. Often there is a disconnect between academic/pilot-scale systems to the full-scale system.

c. There is a need to consider evolving technology. We cannot continue to do things in the same way in the future.

d. New technologies need to be fully implementable to make the economic aspects work

Based on this questioning, it may be difficult to discount the stakeholders who were not mathematically considered consistent. By throwing out two-thirds of a stakeholder group, there is the possibility that important perspectives are removed from consideration. All interviewed stakeholders felt that their prioritizations were correct and therefore represented their viewpoint on end of life MSW systems.

Conclusions

DecisionTogether© showed that the SLCA and AHP integrated methodology worked to aid in the elicitation of diverse stakeholders to evaluate environmental systems, in particular, end of life MSW systems. SLCA allows for the simplification of the system, which is appropriate for the planning stage of an environmental project. AHP allows for the guide evaluation of the criteria, attributes, and alternatives with respect to the goal. Environmental decisions, especially at the community level, should be made by as many stakeholders as possible. This process is not a survey asking for ranking on a numerical scale. Instead, it allows stakeholders to compare all elements in order to prioritize. The DecisionTogether© process is accessible to a diverse group of stakeholders.

The following conclusion and recommendations can be made about the DecisionTogether© methodology:

- It is recommended stakeholders be engaged early on the criteria and attribute development. This way, community concerns can be considered upfront, and

DecisionTogether© provides a means to evaluate and address these concerns or interests.

- The web application for DecisionTogether© allowed stakeholders to participate in the elicitation at their own pace and at their own time.
- An information or training session should be held for all stakeholders. This would provide all stakeholders with the same information about the elicitation and allow them to ask questions. The elicitation can be taken in person as a group or at another time. The stakeholders would have a common understanding of the hierarchy and its objective/goal, criteria, attributes, and alternatives.
- Stakeholders should be provided an opportunity to participate in a training case of the DecisionTogether© process. If participants have a chance to try out the software, they may feel more comfortable with the mechanics of the process and will be able to improve their consistency.

For this research, the group evaluated were not brought together to develop a set of objectives. A list of criteria was developed based on literature review, and experts in MSW managed to participate in a survey to determine if the criterion and alternatives were in line with their opinions.

CHAPTER VI

Conclusions

Summary of Accomplishments

The dissertation first evaluated how LCA and SLCA can be used in the evaluation of environmental systems to aid with future planning. Metro Nashville has a long-term goal to achieve a zero-waste goal of 90 percent diversion. There will always be some percentage of waste that will require final disposal and/or treatment. In the case of Metro Nashville, LCA can be used to inform the goal of providing the most environmentally beneficial means to handle the remaining waste not managed through the zero waste plans. Metro Nashville's utilization of LCA to evaluate end of life MSW systems will allow for short term and long-term consideration of the environmental impacts. The plan for the full implementation of the zero-waste plan in 30 years. But there is no reason that Metro Nashville cannot utilize an environmental-friendly end of life MSW technologies along the way.

Often, in the evaluation of future environmental systems, there is limited information on what a full-scale system would look like. Full LCAs require a large number of inputs to achieve meaningful environmental impact results. This dissertation explained how SLCA could be used in place of a Full LCA in the planning and assessment portion of the evaluation of future systems. SLCA can be used to simplify the boundary and steps of the evaluated system. SLCA requires five steps to be evaluated for five impacts. SLCA requires input from experts to inform the evaluation matrix since they have a working knowledge of the systems and their potential environmental impacts.

Though SLCA was successful at aiding in the simplification of system boundaries, the impact results provided by the experts were varied when averaged together. Only five experts participated in the evaluation, which did not provide a large enough set of results to provide a clear picture of the environmental impacts of each scenario. Based on these results, SLCA should be tested to see how it improves when a greater number of experts can be engaged in the evaluation process. Yet, SLCA is an appropriate tool for use evaluation of future potential environmental systems.

This dissertation developed a novel methodology to integrate SLCA and AHP in the form of DecisionTogether© to allow for the elicitation of diverse stakeholders for the evaluation of environmental planning. DecisionTogether© is intended to create inclusive engagement for communities struggling with difficult environmental decision-making. All stakeholders need a change to present their perspectives and priorities. SLCA provides the means to develop system boundaries, simplify system steps, and simplify system inputs. SLCA is integrated with AHP to provide a means to evaluate criteria that need to be evaluated in the planning for future environmental systems. AHP allows for criteria, including environmental, to be compared in a systematic way with respect to the objective and goal and the scenarios developed for evaluation. DecisionTogether© integrates SCLA and AHP in a way to allow stakeholders to provide input. DecisionTogether© was applied to evaluate the scenarios developed in the LCA/SLCA portion of the dissertation. In addition to the environmental criterion, economics, social acceptance, technical feasibility, and regulatory acceptance was evaluated. DecisionTogether© web application provides a means to engage stakeholders and guide them through the pairwise comparison process. Twenty-one stakeholders participated in this elicitation process.

Consistent pairwise comparisons can be an issue that arises from the use of AHP. Typically, AHP requires that a consistency ratio of 0.1 or 10 percent be used to ensure that stakeholders are consistent when comparing elements at each tier of the hierarchy. Some literature states that a consistency ratio no greater than 0.2 or 20 percent be utilized. Often, stakeholders are asked to return to their answers to evaluate their consistency and work to change their answers to become more consistent has causes stakeholders to change their judgments in such a way as to potentially change their answers and potentially losing their intended prioritizations.

In the elicitation, all stakeholders showed some level of inconsistency in their evaluation of the criteria, attributes, and scenarios. To prevent all stakeholder inputs from being void, the amount of inconsistency was evaluated through comparison with the 0.1 and 0.2 consistency ratio and control charts for the consistency index. Based on this evaluation, eight stakeholders were retained for further consideration. Removing the other stakeholder created some differences in prioritization. Yet, there is the possibility that even if the stakeholders' consistency ratio states that they are mathematically inconsistent, there is the possibility that the stakeholder responses are true to their perspectives and thoughts. When interviewed, both consistent and inconsistent stakeholders felt their prioritizations were current. Therefore, there needs to be some sort of accounting made for how a stakeholder prioritizes their judgments.

Future Work

The developed methodology of DecisionTogether© should be further developed and applied to real-world cases where there is a need to guide the environmental decision-making process. A next step would be to apply DecisionTogether© to a community-specific environmental evaluation. This process would include stakeholder engagement in the criteria and attribute development. The system boundaries would be established using SLCA. The election would be accomplished using the DecisionTogether© web tool.

Elicitation Process

Based on feedback from decision-makers as well as a review of the results, it is recommended that the DecisionTogether© process provide better training. Some of the stakeholders from the decision-making process attended a presentation outlining DecisionTogether© for its application for evaluating end of life MSW systems. But, none of the general public stakeholders participated in the presentation, so, therefore, had the least amount of information provided to them. It the future, DecisionTogether© should be implemented in the following ways:

- Train stakeholders and provide additional background information: During the follow-up interview, general public stakeholders made comments that they lacked the technical expertise to make all the pairwise comparisons. This may apply to additional stakeholders. Prospective stakeholders should attend an informational session that will provide them with background information on the goal/objective, criteria, attributes, and alternatives of the decision to be made. In addition, a video can be accessible to stakeholders to allow them to revisit elements of the elicitation process at their own pace. This would also allow for important stakeholders that are not considered experts to participate in the elicitation process fully.
- Toy case: Some of the inconsistencies seen in the evaluation of the control charts may be due to the lack of experience stakeholders have in the pairwise comparison process. To reduce inconsistency from the lack of familiarity, stakeholders should participate in a mock elicitation for a toy case. The most widely used toy case for AHP is the car example, where a stakeholder is asked to determine which car they should purchase. This case is relatable to all stakeholders and will help illustrate how the DecisionTogether© process works.

- Online resources: A dedicated website should be established for the stakeholders to visit and review the information that will assist with the elicitation process. This could include technical information as well as videos that could provide information on how to complete elicitation and provide background on the DecisionTogether© methodology.
- Stakeholder engagement in the development of criteria, attributes, and scenarios.
- Real-time Elicitation: Allow stakeholders to participate in the decision-making process in the same location, at the same time. This would allow stakeholders to have more support in the elicitation process and could help guide the receiving of information pertinent to the decision-making process.
- Encourage stakeholders to review responses: At the end of Part 1 and 3, stakeholders should be allowed to see their prioritization. If stakeholders do not think this prioritization is correct, they should be allowed to return to the pairwise comparisons to reevaluate the section.

Inconsistency Issues

The concept of consistency ratio and the validity of a stakeholder's judgment needs to be assessed. The dissertation makes the argument that even if a stakeholder has consistency ratio values above 0.1, there is still a level of validity to their perspective of their judgment. It would be of interest to do further research into how you can include all the stakeholders and allow them to show some level of consistency in the judgment process. In addition to this, it should be tested to see how additional training before the elicitation can improve stakeholder's consistency ratios.

Appendix A

Rubric for Streamlined Life Cycle Assessment

2301 Vanderbilt Place
PMB 351826
Nashville, TN 37235-1826

March 3, 2019

Dear Participant,

As part of my dissertation work for my PhD at Vanderbilt University, I am developing an integrated life cycle assessment (LCA) and Analytical Hierarchy Process (AHP) decision methodology for use to evaluate Future End of Life Municipal Solid Waste Technologies. Currently, I have developed a matrix for the evaluation of impacts that result from five simplified stages of municipal solid waste (MSW) management. Your input into the evaluation will be used to inform the environmental impact to be evaluated in the next stage of research, which involves the further development of the decision methodology and elicitation of stakeholders.

The attached document will assist you to evaluate the impacts for three end of life waste management systems. Please review the document thoroughly prior to completion of the evaluation. Section 3.3 provides a rubric to walk you through the elements that require evaluation.

The evaluation will be conducted using the web-based Google Sheet. A link is provided for the completion of the survey. The survey should take 15-30 minutes to complete. Complete the evaluation based on your knowledge and does not require you to review or research answers.

Your participation in this evaluation is completely voluntary and your participation and any personally identifying information will be help confidential. For this research, only your stakeholder designation and responses will be published in further work. The Vanderbilt University Institutional Review Board has approved this evaluation. Should you have any comments or questions, please feel free to contact me at andrea.r.gardiner@vanderbilt.edu or 805-886-1975.

Thanks for your time and participation. The information you provide is valued and important for this research.

Andrea Gardiner, PE
PhD Candidate
Department of Civil and Environmental Engineering
Vanderbilt University

Rubric to Complete Streamlined Life Cycle Assessment for Evaluation of

End of Life Waste Management Systems

Introduction:

This research is part of the dissertation work by Andrea Resch Gardiner as a fulfillment of her degree requirements for Vanderbilt University and will be published within her dissertation. This research evaluates the use of Streamline Life Cycle Assessment (SLCA) to evaluate environmental and energy impacts for three end of life waste management systems for municipal solid waste (MSW) in Middle Tennessee. The results will be used to inform decision makers about environmental impacts in the next research phase.

Evaluated Scenarios:

Three MSW management scenarios (from curb side pick up to end of life management) are being evaluate for environmental and energy impacts. The systems are hypothetical cases based on current Metropolitan Nashville MSW operations and include:

1. Scenario 1: Landfill
2. Scenario 2: Waste to energy facility with associated landfill and
3. Scenario 3: MSW composting with associated landfill

All three scenarios assume that MSW is collected and managed the same way prior to reaching the end of life waste management facility. The SLCA processes include 5 life cycle stages (Figure 1):

1. Collection of Waste: Collection of MSW from residential locations utilizing standard side and rear collection trucks. Once trucks are full, they transport waste to transfer station within the metropolitan area.
2. Management at Transfer Station: Once at the transfer station, collection trucks dump MSW on the tipping floor at the transfer station. MSW is then transferred into trailers for transport to end of life management facilities. The facility is completely enclosed, and any leachate produced is pumped to a municipal wastewater treatment facility for additional treatment.
3. Transportation to End of Life Management Facility: Upon loading the MSW into trailers, it is transported by truck to the end of life management facility. It is assumed that the end of life management facility is located no more than 30 miles from the transfer station.
4. Management at End of Life Facility: Once the MSW has arrived at the end of life facility it is processed and managed. For Scenario 1, MSW is dumped from trailers into the landfill, where it is compacted and covered per regulations. For Scenario 2, MSW is processed and incinerated to produce steam and electricity. Residual materials are disposed at an onsite permitted landfill. For Scenario 3, MSW is processed, separated and composted. Residual materials are disposed at an onsite permitted landfill
5. Long Term Management at End of Life Facility: For Scenarios 1, 2, and 3, long term management includes the collection of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing structures such as collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period.

Environmental Impact Assessment:

The five environmental impact categories evaluated include (1) solid waste managed, (2) energy, (3) air emissions, (4) water emissions, and (5) land impacts. Each impact category relates to the impact, potentially negative or positive, expected to be encountered at each life cycle stage. The impacts are defined as:

1. Solid Waste Managed: the impact relates to the amounts of MSW managed at each life cycle stage. This considers how much waste is disposed of at each life cycle stage. Diverted materials such as recyclable or organic tree waste are not considered in this study are considered separate streams from the MSW.
2. Energy: the impact relates to the amount of energy needed for each life cycle stage, as well as considers any energy production, energy use minimization, or any energy efficiency methods used.
3. Air emissions: the impact relates air emissions for each life cycle stage including effects to air quality based on the emissions produced or avoided.
4. Water emissions: the impact relates water emission for each life cycle stage including effects on water quality (surface and groundwater) based on the emissions produced or avoided.
5. Land Impacts: the impact relates land impacts for each life cycle stage including short term and long-term land uses.

Additional framing of each life cycle stage and impact is provided in the rubric in Attachment A.

Evaluation Process

The evaluation process involves assigning a value of impact from 0 to 4 for each life cycle stage. The value of 0 is given to a matrix box when the life cycle stage is seen as having a significant impact on an environmental stressor (worst case). If a life cycle stage is seen as having no or minimal environmental impact, then a 4 is assigned (best case). Values between 1 and 3 are provided for impacts between the best and worst cases. A rubric is provided In Attachment C for framing additional information. The provided values will be used to calculate a cumulative environmental impact score for each scenario. In the Attachment B, Table 1 presents the general SLCA matrix which will be utilized in this evaluation. The numbers in each box of Table 1 serve as a reference for row and column location within the matrix.

The steps to complete the matrix are as follows:

1. Review the description for the system being evaluated.
2. Review the rubric (Attachment C) for all elements of the matrix in Table 1 (Attachment B).
3. Assign a value of 0 to 4 for each life cycle stage and impact.
4. Iterate Steps 1-3 as necessary until all life cycle stages have an impact value.

The impact values will be inputted into Google Forms (link provided).

ATTACHMENTS

ATTACHMENT A: Figure

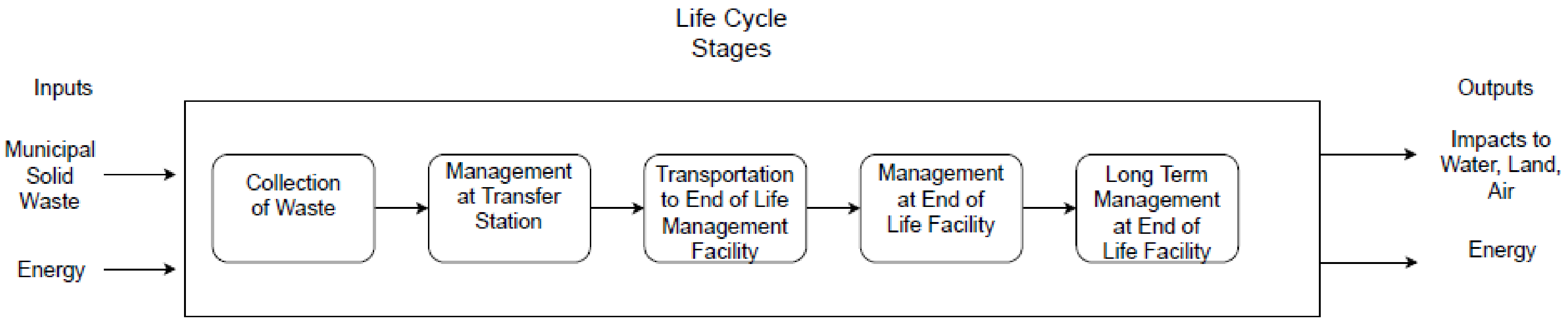

Figure 1 Streamlined Life Cycle Assessment Diagram for MSW System

ATTACHMENT B: Matrix Table

Table 1 Life Cycle Stages and Environmental Stressors for SLCA Evaluation

	Environmental Impact				
Life Cycle Stages	Solid Waste Managed	Energy	Air Emissions	Water Emissions	Land Impacts
Collection of Waste	1,1	1,2	1,3	1,4	1,5
Management at Transfer Station	2,1	2,2	2,3	2,4	2,5
Transportation to End of Life Management Facility	3,1	3,2	3,3	3,4	3,5
Management at End of Life Facility	4,1	4,2	4,3	4,4	4,5
Long Term Management at End of Life Facility	5,1	5,2	5,3	5,4	5,5

ATTACHMENT C: Rubric

Below is a list of all the matrix elements which require answering. For each matrix element, review the text and determine where on number on the 0-4 scale the life stage and environmental impact should assigned to the element.

Rubric for Life Cycle Stage and Environmental Impact Assessment				
Solid Waste Collection				
Matrix Element 1,1: Solid Waste Managed for Collection of Waste	**Life Stage: Collection of Waste** **Environmental Impact: Solid Waste Managed**			
Matrix Rating	0	1-3	4	Rating
	Is all waste disposed of by residential customers collected by the collection vehicles for transport to the transfer station?	If waste is collected, what percentage produced by residential customers is diverted for recycling, reuse, composting, etc. (waste diversion)?	Is all waste diverted to recycling, reuse, composting, etc. facility and not collected by collection vehicle for transport to the transfer station?	
Matrix Element 1,2: Energy for Collection of Waste	**Life Stage: Collection of Waste** **Environmental Impact: Energy**			**Rating**
Matrix Rating	0	1-3	4	
	Do collection and transport methods require use of vehicles which are not energy efficient, such as have low fuel economy? Are vehicles undersized requiring excessive trips? Are routes non-efficient requiring additional miles to be traveled?	Are collections routes designed to minimize fuel/energy usage? Do collection trucks have energy efficient engines/system which reduce the amount of fuel needed to operate?	Are the energy needs negligible to collect and transport waste? Are the routes traveled the most efficient for the collection and transport of waste?	

Rubric for Life Cycle Stage and Environmental Impact Assessment				
Matrix Element 1,3: Air Emissions for Collection of Waste	**Life Stage: Collection of Waste** **Environmental Impact: Air Emissions**			**Rating**
Matrix Rating	0	1-3	4	
	Do the collection vehicles utilize standard combustion systems that have no emission controls? Is waste is collected in open trailers which allow for odors to escape?	Do some of the collection vehicle fleet utilize alternative fuel such as natural gas, with lower air emission than conventional combustion engines? Are the waste materials handled in a way to prevent odors, such as being collected in a partially or completely enclosed vehicles?	Do the collection vehicles produce zero emission? Is waste collected in fully enclosed vehicles?	
Matrix Element 1,4: Water Emissions for Collection of Waste	**Life Stage: Collection of Waste** **Environmental Impact: Water Emissions**	**Rating**		
Matrix Rating	0	1-3	4	
	Do collection vehicles cause the production of excessive leachate due to having open trucks which allow wastes to come into contact with storm water? Is produced leachate discharged without treatment?	What percentage of the collection vehicles are enclosed to prevent leachate formation)? Is collected leachate discharge without treatment?	Are collection vehicles fully enclosed to prevent waste from coming into contact with storm water? Are conditions such that there is no leachate formation?	

Rubric for Life Cycle Stage and Environmental Impact Assessment				
Matrix Element 1,5: Solid Waste Managed for Collection of Waste	**Life Stage: Collection of Waste** **Environmental Impact: Land Impacts**			**Rating**
Matrix Rating	0	1-3	4	
	Is collected waste allow to fall off vehicles and is not picked up and managed? Does transportation allow for litter to be left along transport routes?	What percentage of waste collected is allowed to fall off of the vehicle? If waste falls off the truck, is the litter collected immediately by the vehicle driver or is there a process to allow for the collection of litter?	Is all waste contained in the vehicle so that no waste leaves the vehicle during transport?	

Rubric for Life Cycle Stage and Environmental Impact Assessment				
Management at Transfer Station				
Matrix Element 2,1: Solid Waste Managed at Transfer Station	**Life Stage: Management at Transfer Station** **Environmental Impact: Solid Waste Managed**			
Matrix Rating	0	1-3	4	Rating
	Is waste stored for the longer than regulatory time frame and/or is not hauled off to a final disposal/treatment?	Are wastes stored at the transfer station facility longer than the regulatory time limit? Is waste stored overnight and for many days? Is waste transferred into transport vehicles at the end of the operation day? Are wastes managed in volumes greater than the facilities capabilities? Can the facility manage all wastes brought to the facility?	Is waste managed quickly and transferred into the larger transport trailers with in the regulatory time frames. Is waste on the tipping floor managed/stored in compliance with regulatory limits?	
Matrix Element 2,2: Energy for Management at Transfer Station	**Life Stage: Management at Transfer Station** **Environmental Impact: Energy**			
Matrix Rating	0	1-3	4	Rating
	Does the transfer station operate without utilizing energy efficient or energy saving infrastructure or reduced/zero emission equipment?	Is the transfer station designed to utilize some energy efficient or energy saving infrastructure? Does the transfer station utilize some energy efficient	Does the transfer station operate in a manner to minimize energy consumption by employing energy saving infrastructure or reduced/zero emission equipment?	

Rubric for Life Cycle Stage and Environmental Impact Assessment				
		equipment to managed waste on site?		
Matrix Element 2,3: Air Emissions for Management at Transfer Station	**Life Stage: Management at Transfer Station** **Environmental Impact: Air Emissions**			
Matrix Rating	0	1-3	4	Rating
	Are uncontrolled air emissions generated at the facility? Are all vehicles and equipment at the facility fossil fuel operated? Do vehicles transporting waste to and from the facility idle creating excessive emission when loading/unloading at the facility? Do storage areas allow odors to escape the facility?	Are electric/zero emission equipment and vehicles utilized at the transfer station? What percentage of vehicles are zero emission? Are wastes managed on site in a way to prevent odors for escaping from the facility? What percentage of vehicles transporting waste allowed to idle?	Do vehicles transporting waste to and from the facility turn off (no idling) during time on site? Are only electric/zero emission vehicles operating at the transfer station? Do storage areas prevent odors from escaping the facility?	

Rubric for Life Cycle Stage and Environmental Impact Assessment				
Matrix Element 2,4: Water Emissions for Management at Transfer Station	**Life Stage: Management at Transfer Station** **Environmental Impact: Water Emissions**			
Matrix Rating	0	1-3	4	Rating
	Is leachate produced from transfer station operations discharged directly to the environment with no collection or treatment?	Is leachate collected from transfer station operations and not allowed to discharge to the environment? Is it discharged directly to a sanitary sewer, storm sewer, or surface water feature? Is leachate managed in accordance with regulatory requirements?	Is all leachate collected during transfer station operations managed and discharged to or treated by the appropriate facility?	
Matrix Element 2,5: Solid Waste Management for Management at Transfer Station	**Life Stage: Management at Transfer Station** **Environmental Impact: Land Impacts**			
Matrix Rating	0	1-3	4	Rating
	Are wastes managed and stored outside on uncovered or unpaved surfaces, where they are allowed to interface with soils?	Is waste managed indoors and on paved areas, or is the material stored outside on paved or unpaved areas? Is waste stored longer than the regulatory limit or buried on site?	Do all facility operations take place inside building? Are waste managed to prevent contact with soils outside the building?	

Rubric for Life Cycle Stage and Environmental Impact Assessment				
Transportation to End of Life Management Facility				
Matrix Element 3,1: Solid Waste Managed for Transport to End of Life Management Facility	**Life Stage: Transportation to End of Life Management Facility** **Environmental Impact: Solid Waste Managed**			
Matrix Rating	0	1-3	4	Rating
	Does all waste stay at facility and is not transported to end of life management facility?	Is some fraction of waste not transported to end of life management facility? Is waste transferred directly from transfer station to end of life management facility or is it transported to an interim location prior to final management?	Are all wastes managed at the transfer station is transported directly to end of life management facility? Are some waste diverted to recycling/reuse facilities?	

Rubric for Life Cycle Stage and Environmental Impact Assessment				
Matrix Element 3,2: Energy for Transport to End of Life Management Facility	**Life Stage: Transportation to End of Life Management Facility** **Environmental Impact: Energy**			
Matrix Rating	0	1-3	4	Rating
	Does transport utilize non-efficient trucks, which may be undersized or are required to stop on route to the end of life management facility? Are additional trips needed to transport waste or are route inefficient? Do the vehicles utilize only fossil fuels?	Are transport routes designed to minimize fuel/energy usage? Do transport trucks have energy efficient engines/system which reduce the amount of fuel needed to operate? Do vehicles utilize more energy efficient alternative fuels?	Is negligible energy needed to transport waste? Is waste transported in the most energy efficient vehicles? Is waste transported in a direct, efficient path?	
Matrix Element 3,3: Air Emissions for Transport to End of Life Management Facility	**Life Stage: Transportation to End of Life Management Facility** **Environmental Impact: Air Emissions**			
Matrix Rating	0	1-3	4	Rating
	Do the transport vehicles utilize standard combustion systems that have no emission controls? Is waste transported in open trailers which allow for odors to escape?	Do some of the transport vehicle in the fleet utilize alternative fuel such as natural gas or other lower air emission fuels? Are the waste materials handled in a way to prevent odors, such as being transported in partially or completely enclosed trailers?	Do the transport vehicles produce zero emission? Is waste collected in fully enclosed trailers?	

Rubric for Life Cycle Stage and Environmental Impact Assessment				
Matrix Element 3,4: Water Emissions for Transport to End of Life Management Facility	**Life Stage: Transportation to End of Life Management Facility** **Environmental Impact: Water Emissions**			
Matrix Rating	0	1-3	4	Rating
	Do the transportation vehicles cause the production of excessive leachate based on waste exposure to storm water because waste is transported in open vehicles? Is leachate discharged with no treatment?	Is some leachate produced based on the type of trailer used (what percentage of the trailer is open to the environment)? Does the leachate go through some type of pretreatment prior to discharge to the wastewater treatment plant? Is leachate discharged to an appropriate discharge point or is it discharged directly to the environment?	Do the transportation vehicles prevent or reduce the formation of leachate by fully enclosing the trailers? Is collected leachate discharged in an appropriate manner?	
Matrix Element 3,5: Solid Waste Managed for Transport to End of Life Management Facility	**Life Stage: Transportation to End of Life Management Facility** **Environmental Impact: Land Impacts**			
Matrix Rating	0	1-3	4	Rating
	Do the trailers allow waste to fall off trucks while being transported and waste is not picked up and managed?	Does some fraction of managed waste fall off of the trailer? Is waste that leaves the trailer left and not collected for prior disposal?	Does waste stay in the vehicle trailers during transport and is not illegally disposed of or dumped prior to management at end of life management facility?	

Rubric for Life Cycle Stage and Environmental Impact Assessment				
Management at End of Life Management Facility: Scenario 1 Landfill				
Matrix Element 4,1: Solid Waste Managed for End of Life Management	Life Stage: Management at End of Life Management Facility Environmental Impact: Solid Waste Managed			
Matrix Rating	0	1-3	4	Rating
	Does the facility have issues which prevents it waste from being managed per regulatory requirements? Is waste is stored on site prior to being placed in the landfill? Are additional solid waste or solid waste constituents are produced, which required additional handling or treatment?	Does the facility manage wastes in accordance with regulatory requirements a majority of the time? Are wastes stored or managed outside the limits of the facility or operational areas?	Does the facility allow for immediate management of waste and operates in accordance with regulatory requirements?	

Rubric for Life Cycle Stage and Environmental Impact Assessment				
Matrix Element 4,2: Energy for End of Life Management	Life Stage: Management at End of Life Management Facility Environmental Impact: Energy			
Matrix Rating	0	1-3	4	Rating
	Do the methods of waste management utilized at the facility require non energy efficient equipment or infrastructure? Does the facility more energy that it produces?	Does the facility utilize energy efficient equipment to managed waste on site? Does the facility utilize energy saving infrastructure? Does the facility produce energy?	Does the facility operate to minimize energy consumption to the limits of available technology? Does the facility utilize energy efficient vehicles and infrastructure in daily operations?	
Matrix Element 4,3: Air Emissions for End of Life Management	Life Stage: Management at End of Life Management Facility Environmental Impact: Air Emissions			
Matrix Rating	0	1-3	4	Rating
	Is waste managed in a way that allows for the generation of air emissions? Do the vehicles and equipment at the facility utilize fossil fuels? Do the vehicles delivering waste to the facility idle allowing additional emission production?	Are electric/zero emission equipment and vehicles utilized at the facility? Are wastes managed on site in a way to prevent air emissions to the environment?	Do vehicles delivering wastes to the facility turn off engines off during time on site, not producing additional emissions? Are electrical/zero emission vehicles utilized at the facility? Are wastes managed to prevent the creation of air emissions or odors which could escape the facility?	

Rubric for Life Cycle Stage and Environmental Impact Assessment				
Matrix Element 4,4: Water Emissions for End of Life Management	Life Stage: Management at End of Life Management Facility Environmental Impact: Water Emissions			
Matrix Rating	0	1-3	4	Rating
	Is leachate produced from facility operations discharged directly to the environment with no collection or treatment?	Is leachate produced and if so, is it collected? Is leachate managed on site in a way to prevent discharge to the environment? Is it discharged directly to a sanitary sewer, storm sewer, or surface water feature? Is leachate managed in accordance with regulatory requirements?	Is there no leachate production at the facility?	
Matrix Element 4,5: Land Impacts for End of Life Management	Life Stage: Management at End of Life Management Facility Environmental Impact: Land Impacts			
Matrix Rating	0	1-3	4	Rating
	Are wastes managed and stored outside operations/treatment area and impact soils?	Is waste able to leave the Facility and come in contact with surrounding area that are not permitted or appropriate for managing wastes? Are residuals from facility processes managed outside of the facility and impact surrounding land?	Do operations prevent impact outside the operations/treatment area and prevent impact to soils? Are only actively permitted areas are utilized for waste management?	

Rubric for Life Cycle Stage and Environmental Impact Assessment				
Long Term Management at End of Life Facility: Scenario 1 Landfill				
Matrix Element 5,1: Solid Waste Managed for Long Term End of Life Management	Life Stage: Long Term Management at End of Life Facility Environmental Impact: Solid Waste Managed			
Matrix Rating	0	1-3	4	Rating
	Is the final waste disposal method temporary and does not allow for permanent management? Does final disposal allow for wastes and associated constituents to become exposed to the environment again?	Does long term management of wastes allow for them to leave the final management system and come into contact with the environment? Is additional waste created during long term management?	Does final disposal keep all solid waste and associated constituents from leaving facility, being exposed, and coming into contact with the environment?	
Matrix Element 5,2: Energy for Long Term End of Life Management	Life Stage: Management at End of Life Facility Environmental Impact: Energy			
Matrix Rating	0	1-3	4	Rating
	Does facility continue to use energy for operations and maintenance and does not produce any energy?	Does the facility utilize energy for continued management? Is energy efficient equipment used to manage end of life management systems? Does the facility produce energy to offset energy needs?	Does the facility produce enough energy to allow for continued operation and does not require external energy use?	

Rubric for Life Cycle Stage and Environmental Impact Assessment				
Matrix Element 5,3: Air Emissions for Long Term End of Life Management	Life Stage: Long Term Management at End of Life Facility Environmental Impact: Air Emissions			
Matrix Rating	0	1-3	4	Rating
	Does long term management of waste allow for uncontrolled emission generation? Are vehicles and equipment utilized at the facility are fossil fuel operated? Are air emissions generated from end of life management discharge to the environment without any treatment?	Are produced air emissions treated prior to discharge? What is the reduction in emissions due to treatment? Are electric/zero emission equipment and vehicles utilized at the facility?	Does long term management of waste prevent all uncontrolled emission generation? Do vehicles and equipment at the facility produce zero emissions? Are no air emissions generated from end of life management discharge to the environment without any treatment?	
Matrix Element 5,4: Water Emissions for Long Term End of Life Management	Life Stage: Long Term Management at End of Life Facility Environmental Impact: Water Emissions			
Matrix Rating	0	1-3	4	Rating
	Is leachate produced from long term management discharged directly to the environment without collection or treatment?	Is leachate produced? Is leachate collected from facility operations/long term management activities? Is leachate managed on site in a way to prevent discharge to the environment? Is it discharged directly to a	Is there any leachate produced from long term operations?	

Rubric for Life Cycle Stage and Environmental Impact Assessment				
		sanitary sewer, storm sewer, or surface water feature? Is leachate managed in accordance with regulatory requirements?		
Matrix Element 5,5: Solid Waste Managed for Long Term End of Life Management	Life Stage: Long Term Management at End of Life Facility Environmental Impact: Land Impacts			
Matrix Rating	0	1-3	4	Rating
	Are wastes able to leave the facility during long term management activities and impact soils? After the facility is closed, residuals are left at the facility location outside of permitted areas?	During long term management, is waste or waste residuals left at the facility site? Does final waste managed have the ability to leave the facility and come in contact with surrounding area that are not permitted or appropriate for managing wastes? Are residuals from facility processes managed outside of the facility and impact surrounding land?	Do the operations prevent any impact to outside of the facility outside? Are there no residuals left after cessation of operations? Is the facility land able to be redeveloped at some point?	

Management at End of Life Management Facility: Scenario 2 Waste to Energy with Landfill				
Matrix Element 4,1: Solid Waste Managed for End of Life Management	Life Stage: Management at End of Life Management Facility Environmental Impact: Solid Waste Managed			
Matrix Rating	0	1-3	4	Rating
	Does the facility have issues which prevents it waste from being managed per regulatory requirements? Is waste is stored on site prior to being placed in the landfill? Are additional solid waste or solid waste constituents are produced, which required additional handling or treatment?	Does the facility manage wastes in accordance with regulatory requirements a majority of the time? Are wastes stored or managed outside the limits of the facility or operational areas?	Does the facility allow for immediate management of waste and operates in accordance with regulatory requirements?	
Matrix Element 4,2: Energy for End of Life Management	Life Stage: Management at End of Life Management Facility Environmental Impact: Energy			
Matrix Rating	0	1-3	4	Rating
	Do the methods of waste management utilized at the facility require non energy efficient equipment or infrastructure? Does the facility more energy that it produces?	Does the facility utilize energy efficient equipment to managed waste on site? Does the facility utilize energy saving infrastructure? Does the facility produce energy?	Does the facility operate to minimize energy consumption to the limits of available technology? Does the facility utilize energy efficient vehicles and infrastructure in daily operations?	

Matrix Element 4,3: Air Emissions for End of Life Management	Life Stage: Management at End of Life Management Facility Environmental Impact: Air Emissions			
Matrix Rating	0	1-3	4	Rating
	Is waste managed in a way that allows for the generation of air emissions? Do the vehicles and equipment at the facility utilize fossil fuels? Do the vehicles delivering waste to the facility idle allowing additional emission production?	Are electric/zero emission equipment and vehicles utilized at the facility? Are wastes managed on site in a way to prevent air emissions to the environment?	Do vehicles delivering wastes to the facility turn off engines off during time on site, not producing additional emissions? Are electrical/zero emission vehicles utilized at the facility? Are wastes managed to prevent the creation of air emissions or odors which could escape the facility?	
4,4: Water Emissions for End of Life Management	Life Stage: Management at End of Life Management Facility Environmental Impact: Water Emissions			
Matrix Rating	0	1-3	4	Rating
	Is leachate produced from facility operations discharged directly to the environment with no collection or treatment?	Is leachate produced and if so, is it collected? Is leachate managed on site in a way to prevent discharge to the environment? Is it discharged directly to a sanitary sewer, storm sewer, or surface water feature? Is leachate managed in accordance with regulatory requirements?	Is there no leachate production at the facility?	

Matrix Element 4,5: Solid Waste Managed for End of Life Management	Life Stage: Management at End of Life Management Facility Environmental Impact: Land Impacts			
Matrix Rating	0	1-3	4	Rating
	Are wastes managed and stored outside operations/treatment area and impact soils?	Is waste able to leave the Facility and come in contact with surrounding area that are not permitted or appropriate for managing wastes? Are residuals from facility processes managed outside of the facility and impact surrounding land?	Do operations prevent impact outside the operations/treatment area and prevent impact to soils? Are only actively permitted areas are utilized for waste management?	

Long Term Management at End of Life Management Facility: Scenario 2 Waste to Energy with Landfill				
Matrix Element 5,1: Solid Waste Managed for Long Term End of Life Management	Life Stage: Long Term Management at End of Life Management Facility Environmental Impact: Solid Waste Managed			
Matrix Rating	0	1-3	4	Rating
	Is the final waste disposal method temporary and does not allow for permanent management? Does final disposal allow for wastes and associated constituents to become exposed to the environment again?	Does long term management of wastes allow for them to leave the final management system and come into contact with the environment? Is additional waste created during long term management?	Does final disposal keep all solid waste and associated constituents from leaving facility, being exposed, and coming into contact with the environment?	
Matrix Element 5,2: Energy for Long Term End of Life Management	Life Stage: Management at End of Life Management Facility Environmental Impact: Energy			
Matrix Rating	0	1-3	4	Rating
	Does facility continue to use energy for operations and maintenance and does not produce any energy?	Does the facility utilize energy for continued management? Is energy efficient equipment used to manage end of life management systems? Does the facility produce energy to offset energy needs?	Does the facility produce enough energy to allow for continued operation and does not require external energy use?	

Matrix Element 5,3: Air Emissions for Long Term End of Life Management	Life Stage: Long Term Management at End of Life Management Facility Environmental Impact: Air Emissions			
Matrix Rating	0	1-3	4	Rating
	Does long term management of waste allow for uncontrolled emission generation? Are vehicles and equipment utilized at the facility are fossil fuel operated? Are air emissions generated from end of life management discharge to the environment without any treatment?	Are produced air emissions treated prior to discharge? What is the reduction in emissions due to treatment? Are electric/zero emission equipment and vehicles utilized at the facility?	Does long term management of waste prevent all uncontrolled emission generation? Do vehicles and equipment at the facility produce zero emissions? Are no air emissions generated from end of life management discharge to the environment without any treatment?	
Matrix Element 5,4: Water Emissions for Long Term End of Life Management	Life Stage: Long Term Management at End of Life Management Facility Environmental Impact: Water Emissions			
Matrix Rating	0	1-3	4	Rating
	Is leachate produced from long term management discharged directly to the environment without collection or treatment?	Is leachate produced? Is leachate collected from facility operations/long term management activities? Is leachate managed on site in a way to prevent discharge to the environment? Is it discharged directly to a sanitary sewer, storm sewer, or surface water feature?	Is there any leachate produced from long term operations?	

		Is leachate managed in accordance with regulatory requirements?		
Matrix Element 5,5: Solid Waste Managed for Long Term End of Life Management	Life Stage: Long Term Management at End of Life Management Facility Environmental Impact: Land Impacts			
Matrix Rating	0	1-3	4	Rating
	Are wastes able to leave the facility during long term management activities and impact soils? After the facility is closed, residuals are left at the facility location outside of permitted areas?	During long term management, is waste or waste residuals left at the facility site? Does final waste managed have the ability to leave the facility and come in contact with surrounding area that are not permitted or appropriate for managing wastes? Are residuals from facility processes managed outside of the facility and impact surrounding land?	Do the operations prevent any impact to outside of the facility outside? Are there no residuals left after cessation of operations? Is the facility land able to be redeveloped at some point?	

Management at End of Life Management Facility: Scenario 3 MSW Composting with Landfill				
Matrix Element 4,1: Solid Waste Managed for End of Life Management	Life Stage: Management at End of Life Management Facility Environmental Impact: Solid Waste Managed			
Matrix Rating	0	1-3	4	Rating
	Does the facility have issues which prevents it from being managed per regulatory requirements? Is waste is stored on site prior to being placed in the landfill? Are additional solid waste or solid waste constituents are produced, which required additional handling or treatment?	Does facility manage wastes in accordance with regulatory requirements majority of the time? Are wastes stored or managed outside the limits of the facility or operational areas?	Does the facility allow for immediate management of waste and operates in accordance with regulatory requirements?	
Matrix Element 4,2: Energy for End of Life Management	Life Stage: Management at End of Life Management Facility Environmental Impact: Energy			
Matrix Rating	0	1-3	4	Rating
	Do the methods of waste management utilized at the facility require non-efficient equipment or infrastructure? Does the facility more energy that it produces?	Does the facility utilize energy efficient equipment to managed waste on site? Does the facility utilize energy saving infrastructure? Does the facility produce energy?	Does the facility operate to minimize energy consumption to the limits of available technology? Does the facility utilize energy efficient vehicles and infrastructure in daily operations?	

Matrix Element 4,3: Air Emissions for End of Life Management	Life Stage: Management at End of Life Management Facility Environmental Impact: Air Emissions			
Matrix Rating	0	1-3	4	Rating
	Is waste managed in a way that allows for generation emissions? Do the vehicles and equipment at the facility utilize fossil fuels? Do the vehicles delivering waste to the facility idle allowing additional emission production?	Are electric/zero emission equipment and vehicles utilized at the facility? Are wastes managed on site in a way to prevent air emissions to the environment?	Are vehicles delivering wastes to the facility are turned off during time on site, not producing emissions? Are electrical/zero emission vehicles utilized at the facility? Are managed wastes prevented is not allowed to create air emissions or odors which could escape the facility?	
4,4: Water Emissions for End of Life Management	Life Stage: Management at End of Life Management Facility Environmental Impact: Water Emissions			
Matrix Rating	0	1-3	4	Rating
	Is leachate produced from facility operations discharged directly to the environment with no collection or treatment?	Is leachate produced and if so, is it collected? Is leachate managed on site in a way to prevent discharge to the environment? Is it discharged directly to a sanitary sewer, storm sewer, or surface water feature? Is leachate managed in accordance with regulatory requirements?	Is there no leachate produced at the facility?	

Matrix Element 4,5: Solid Waste Managed for End of Life Management	Life Stage: Management at End of Life Management Facility Environmental Impact: Land Impacts			
Matrix Rating	0	1-3	4	Rating
	Are wastes managed and stored outside operations/treatment area and impact soils?	Is waste able to leave the facility and come in contact with surrounding area that are not permitted or appropriate for managing wastes? Are residuals from facility processes managed outside of the facility and impact surrounding land?	Do operations prevent impact outside the operations/treatment area and impact soils? Are only actively permitted areas are utilized for waste management?	

Long Term Management at End of Life Management Facility: Scenario 3 MSW Composting with Landfill				
Matrix Element 5,1: Solid Waste Managed for Long Term End of Life Management	Life Stage: Long Term Management at End of Life Management Facility Environmental Impact: Solid Waste Managed			
Matrix Rating	0	1-3	4	Rating
	Is the final waste disposal method temporary and does not allow for permanent management? Does final disposal allow for wastes and associated constituents to become exposed to the environment again?	Does long term management of wastes allow for them to leave the final management system and come into contact with the environment? Is additional waste created during long term management?	Does final disposal keep all solid waste and associated constituents from leaving facility, being exposed, and coming into contact with the environment?	
Matrix Element 5,2: Energy for Long Term End of Life Management	Life Stage: Management at End of Life Management Facility Environmental Impact: Energy			
Matrix Rating	0	1-3	4	Rating
	Does facility continue to use energy for operations and maintenance and does not produce any energy?	Does the facility utilize energy for continued management? Is energy efficient equipment used to manage end of life management systems? Does the facility produce energy to offset energy needs?	Does the facility produce enough energy to allow for continued operation and does not require external energy use?	

Matrix Element 5,3: Air Emissions for Long Term End of Life Management	Life Stage: Long Term Management at End of Life Facility Environmental Impact: Air Emissions			
Matrix Rating	0	1-3	4	Rating
	Does long term management of waste allow for uncontrolled emission generation? Are utilized vehicles and equipment at the facility are fossil fuel operated? Are air emissions generated from end of life management discharge to the environment without any treatment?	Are produced air emissions treated prior to discharge? What is the reduction in emissions due to treatment? Are electric/zero emission equipment and vehicles utilized at the facility?	Does long term management of waste prevent all uncontrolled emission generation? Do vehicles and equipment at the facility produce zero emissions? Are no air emissions generated from end of life management discharge to the environment without any treatment?	
Matrix Element 5,4: Water Emissions for Long Term End of Life Management	Life Stage: Long Term Management at End of Life Facility Environmental Impact: Water Emissions			
Matrix Rating	0	1-3	4	Rating
	Is leachate produced from long term management discharged directly to the environment without collection or treatment.	Is leachate produced? Is leachate collected from Facility operations/long term management activities? Is leachate managed on site in a way to prevent discharge to the environment? Is it discharged directly to a	Is there any leachate produced from long term operations?	

		sanitary sewer, storm sewer, or surface water feature? Is leachate managed in accordance with regulatory requirements?		
Matrix Element 5,5: Solid Waste Managed for Long Term End of Life Management	Life Stage: Long Term Management at End of Life Facility Environmental Impact: Land Impacts			
Matrix Rating	0	1-3	4	Rating
	Are wastes able to leave the facility during long term management activities and impact soils? After the facility is closed, residuals are left at the facility location outside of permitted areas?	During long term management, is waste or waste residuals left at the facility site? Does final waste managed have the ability to leave the facility and come in contact with surrounding area that are not permitted or appropriate for managing wastes? Are residuals from facility processes managed outside of the facility and impact surrounding land?	Do the operations prevent any impact to outside of the facility outside? Are there no residuals left after cessation of operations? Is the facility land able to be redeveloped at some point?	

ATTACHMENT D: References

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Appendix B

Results from Streamline Life Cycle Assessment Expert Elicitation

Results for Scenario 1: Landfill

Scenario 1 involved the evaluation of life cycle and environmental impacts for a landfill. The life cycle stages included : collection of waste, management at transfer station, transportation to end of life management facility, end of life management, and long term management at end of life. The environmental impacts included solid waste managed, energy, air emissions, water emissions, and land impacts.

Expert 1 identified as a Solid Waste Authority/County Solid Waste Director/and or Operator. Expert 1's results for Scenario 1 are shown in Table 2. The total score for the matrix was 56.

Table 2 Expert 1 Results for SLCA for Scenario 1

Life Cycle Stage	Solid Waste Managed	Energy	Air Emissions	Water Emissions	Land Impacts	Sum
Collection of Waste	2	2	2	1	3	10
Management at Transfer Station	3	1	1	2	3	10
Transportation to End of Life Management Facility	3	2	2	2	4	13
End of Life Management	3	2	1	2	3	11
Long Term Management at End of Life	3	2	3	2	2	12
Sum	14	9	9	9	15	56

Expert 2 identified as a Solid Waste Authority/County Solid Waste Director/and or Operator. Expert 2's results for Scenario 1 are shown in Table 2. The total score for the matrix was 72.

Table 3 Expert 1 Results for SLCA for Scenario 1

Life Cycle Stage	Solid Waste Managed	Energy	Air Emissions	Water Emissions	Land Impacts	Sum
Collection of Waste	2	1	2	3	3	11
Management at Transfer Station	4	3	1	4	4	16
Transportation to End of Life Management Facility	4	2	2	3	3	14
End of Life Management	4	2	3	3	4	16
Long Term Management at End of Life	4	2	4	2	3	15
Sum	18	10	12	15	17	72

Expert 3 identified as a Corporate Landfill Manager/Operator. Expert 3's results for Scenario 1 are shown in Table 4. The total score for the matrix was 49.

Table 4 Expert 3 Results for SLCA for Scenario 1

Life Cycle Stage	Solid Waste Managed	Energy	Air Emissions	Water Emissions	Land Impacts	Sum
Collection of Waste	2	1	3	3	4	13
Management at Transfer Station	2	2	1	2	3	10
Transportation to End of Life Management Facility	2	1	3	3	4	13
End of Life Management	1	1	1	1	0	4
Long Term Management at End of Life	1	3	2	2	1	9
Sum	8	8	10	11	12	49

Expert 4 identified as a Regulator. Expert 4's results for Scenario 1 are shown in Table 5. The total score for the matrix was 42.

Table 5 Expert 4 Results for SLCA for Scenario 1

Life Cycle Stage	Solid Waste Managed	Energy	Air Emissions	Water Emissions	Land Impacts	Sum
Collection of Waste	1	2	2	2	4	11
Management at Transfer Station	1	2	2	2	3	10
Transportation to End of Life Management Facility	0	3	1	1	1	6
End of Life Management	0	3	1	1	1	6
Long Term Management at End of Life	1	3	2	2	1	9
Sum	3	13	8	8	10	42

Expert 5 identified as a Regulator. Expert 5's results for Scenario 1 are shown in Table 6. The total score for the matrix was 29.

Table 6 Expert 5 Results for SLCA for Scenario 1

Life Cycle Stage	Solid Waste Managed	Energy	Air Emissions	Water Emissions	Land Impacts	Sum
Collection of Waste	0	0	4	3	0	7
Management at Transfer Station	0	0	4	2	3	9
Transportation to End of Life Management Facility	0	2	0	0	0	2
End of Life Management	0	2	0	0	0	2
Long Term Management at End of Life	1	2	0	3	3	9
Sum	1	6	8	8	6	29

Results for Scenario 2:

Scenario 2 involved the evaluation of life cycle and environmental impacts for a Waste to energy facility with associated landfill. The life cycle stages included : collection of waste, management at transfer station, transportation to end of life management facility, end of life management, and long term management at end of life. The environmental impacts included solid waste managed, energy, air emissions, water emissions, and land impacts.

Expert 1's results for Scenario 2 are shown in Table 7. The total score for the matrix was 64.

Table 7 Expert 1 Results for SLCA for Scenario 2

Life Cycle Stage	Solid Waste Managed	Energy	Air Emissions	Water Emissions	Land Impacts	Sum
Collection of Waste	2	2	2	1	3	10
Management at Transfer Station	3	1	1	2	3	10
Transportation to End of Life Management Facility	3	2	2	2	4	13
End of Life Management	3	3	3	3	3	15
Long Term Management at End of Life	3	4	3	3	3	16
Sum	14	12	11	11	16	64

Expert 2's results for Scenario 2 are shown in Table 8. The total score for the matrix was 75.

Table 8 Expert 2 Results for SLCA for Scenario 2

Life Cycle Stage	Solid Waste Managed	Energy	Air Emissions	Water Emissions	Land Impacts	Sum
Collection of Waste	2	1	2	3	3	11
Management at Transfer Station	4	3	1	4	4	16
Transportation to End of Life Management Facility	4	2	2	3	3	14
End of Life Management	4	3	3	3	4	17
Long Term Management at End of Life	4	3	3	3	4	17
Sum	18	12	11	16	18	75

Expert 3's results for Scenario 2 are shown in Table 9. The total score for the matrix was 50.

Table 9 Expert 3 Results for SLCA for Scenario 2

Life Cycle Stage	Solid Waste Managed	Energy	Air Emissions	Water Emissions	Land Impacts	Sum
Collection of Waste	2	1	3	3	4	13
Management at Transfer Station	2	2	1	2	3	10
Transportation to End of Life Management Facility	2	1	3	3	4	13
End of Life Management	1	0	1	2	2	6
Long Term Management at End of Life	1	1	2	2	2	8
Sum	8	5	10	12	15	50

Expert 4's results for Scenario 2 are shown in Table 10. The total score for the matrix was 38.

Table 1030 Expert 4 Results for SLCA for Scenario 1

Life Cycle Stage	Solid Waste Managed	Energy	Air Emissions	Water Emissions	Land Impacts	Sum
Collection of Waste	1	2	2	2	4	11
Management at Transfer Station	1	2	2	2	3	10
Transportation to End of Life Management Facility	0	3	1	1	1	6
End of Life Management	0	1	1	1	1	4
Long Term Management at End of Life	2	1	1	1	2	7
Sum	4	9	7	7	11	38

5's results for Scenario 2 are shown in Table 11. The total score for the matrix was 32.

Table 11 Expert 5 Results for SLCA for Scenario 1

Life Cycle Stage	Solid Waste Managed	Energy	Air Emissions	Water Emissions	Land Impacts	Sum
Collection of Waste	0	0	4	3	0	7
Management at Transfer Station	0	0	4	2	3	9
Transportation to End of Life Management Facility	0	2	0	0	0	2
End of Life Management	2	0	0	2	2	6
Long Term Management at End of Life	2	0	0	3	3	8
Sum	4	2	8	10	8	32

Results for Scenario 3:

Scenario 3 involved the evaluation of life cycle and environmental impacts for a municipal solid waste composting facility with associated landfill. The life cycle stages included : collection of waste, management at transfer station, transportation to end of life management facility, end of life management, and long term management at end of life. The environmental impacts included solid waste managed, energy, air emissions, water emissions, and land impacts.

Expert 1's results for Scenario 3 are shown in Table 12. The total score for the matrix was 55.

Table 12 Expert 1 Results for SLCA for Scenario 3

Life Cycle Stage	Solid Waste Managed	Energy	Air Emissions	Water Emissions	Land Impacts	Sum
Collection of Waste	2	2	2	1	3	10
Management at Transfer Station	3	1	1	2	3	10
Transportation to End of Life Management Facility	3	2	2	2	4	13
End of Life Management	2	1	2	3	2	10
Long Term Management at End of Life	2	2	2	3	3	12
Sum	12	8	9	11	15	55

Expert 2's results for Scenario 3 are shown in Table 13. The total score for the matrix was 70.

Table 13 Expert 2 Results for SLCA for Scenario 3

Life Cycle Stage	Solid Waste Managed	Energy	Air Emissions	Water Emissions	Land Impacts	Sum
Collection of Waste	2	2	2	1	3	10
Management at Transfer Station	4	3	1	4	4	16
Transportation to End of Life Management Facility	4	2	2	3	3	14
End of Life Management	4	2	3	3	3	15
Long Term Management at End of Life	4	2	3	3	3	15
Sum	18	11	11	14	16	70

Expert 3's results for Scenario 3 are shown in Table 14. The total score for the matrix was 53.

Table 14 Expert 3 Results for SLCA for Scenario 2

Life Cycle Stage	Solid Waste Managed	Energy	Air Emissions	Water Emissions	Land Impacts	Sum
Collection of Waste	2	1	3	3	4	13
Management at Transfer Station	2	2	1	2	3	10
Transportation to End of Life Management Facility	2	1	3	3	4	13
End of Life Management	1	1	2	2	2	8
Long Term Management at End of Life	2	3	2	1	1	9
Sum	9	8	11	11	14	53

Expert 4’s results for Scenario 2 are shown in Table 15. The total score for the matrix was 38.

Table 15 Expert 4 Results for SLCA for Scenario 1

Life Cycle Stage	Solid Waste Managed	Energy	Air Emissions	Water Emissions	Land Impacts	Sum
Collection of Waste	1	2	2	2	4	11
Management at Transfer Station	1	2	2	2	3	10
Transportation to End of Life Management Facility	0	3	1	1	1	6
End of Life Management	0	1	1	1	1	4
Long Term Management at End of Life	2	1	1	1	2	7
Sum	4	9	7	7	11	38

Expert 5’s results for Scenario 3 are shown in Table 16. The total score for the matrix was 32.

Table 16 Expert 5 Results for SLCA for Scenario 1

Life Cycle Stage	Solid Waste Managed	Energy	Air Emissions	Water Emissions	Land Impacts	Sum
Collection of Waste	0	0	4	3	0	7
Management at Transfer Station	0	0	4	2	3	9
Transportation to End of Life Management Facility	0	2	0	0	0	2
End of Life Management	2	0	0	2	2	6
Long Term Management at End of Life	2	0	0	3	3	8
Sum	4	2	8	10	8	32

Appendix C

Stakeholder Elicitation for Criteria

Future End of Life Municipal Solid Waste Technology Evaluation

Dear participant,

As part of my dissertation work at Vanderbilt University in the Department of Civil and Environmental Engineering, I am working to develop a decision tool which will be used to help evaluate end of life municipal solid waste technologies by considering a variety of technologies and the criteria used to evaluate them. These alternatives and criteria will be integrated into a decision tool which will be used to help a variety of stakeholders come to consensus on the criteria and technologies.

This survey will be used in an academic research study to develop a multicriteria decision tool to evaluate end of life municipal solid waste technologies. This tool will collect information for stakeholders to use in developing consensus for future technologies. This is currently a need as local landfill capacity is finite and new end of life waste management facilities will be needed to handle municipal solid waste. In this work, end of life waste management technologies will be evaluated based on the following criteria: economics, environmental, social, technical feasibility, and regulatory acceptance.

The goal of this survey is to identify the most important attributes considered by stakeholders when making plans for future solid waste management end of life solutions. Please take a moment to complete the survey. The results of the survey are anonymous. No personal information, such as email addresses and names will be published as part of this research.

Andrea Resch Gardiner, PE

Vanderbilt University

1. What sector do you primarily identify with as a participant in this survey (select one)?

    __ Regulator
    __ County/City Government Official
    __ Solid Waste Authority/County Solid Waste Director and/or Operator
    __ Academic
    __ General Public
    __ Corporate Landfill Manager/Operator
    __ Other:
    Please State:

2. Please provide your email address:________________________
    Would you be interested in participating in future elicitations related to this work:

    __ Yes

    __ No

3. Please review and rank the following end of life waste management technologies from the most preferred end of life technologies for municipal solid waste (from “1” being most preferred to “5” being least preferred):

    ___ Class I Municipal Solid Waste Landfill
    ___ Incineration
    ___Waste to Energy
    ___ Anaerobic Digestion
    ___ MSW Composting

4. Please provide any additional technologies that should also be considered in this study:
    ____

5. Please review and rank the following overall criteria for used in the evaluation of end of life technologies for municipal solid waste (from “1” being most preferred to “5” being least preferred):

___ Economics
___ Environmental
___ Social Acceptance
___ Technical Feasibility
___ Regulatory Acceptance

6. If additional attributes should be considered, please provide additional information:

7. Please review and rank the following attributes for consideration in evaluating the Economic criteria (from “1” being most preferred to “5” being least preferred):

___ Capital Investment Costs
___ Operational and Maintenance Costs
___ Economic Impact on Subscribers in Surrounding Communities
___ Economic Incentives for Communities Surrounding Facility
___ Property Values Around Facility

8. If additional attributes should be considered, please provide additional information:

9. Please review and rank the following attributes for consideration in evaluating the Environment criteria (from “1” being most preferred to “4” being least preferred):

___ Impact to Water
___ Impact to Air
___ Impact to Land

10. ___ If additional attributes should be considered, please provide additional information:

11. Please review and rank the following attributes for consideration in evaluating the Social criteria (from “1” being most preferred to “4” being least preferred):
___ Employment
___ Social Acceptance
___ Noise/Odor

12. If additional attributes should be considered, please provide additional information:

13. Please review and rank the following attributes for consideration in evaluating the Technical Feasibility criteria (from “1” being most preferred to “8” being least preferred):

___ Availability of Land for Facility
___ Energy Consumption
___ Energy Production

___ Life Expectancy of Facility
___ Distance form Community/Transfer Station
___ Beneficial Reuse/Resource Conservation
___ Implementability
___ Available Infrastructure

14. If additional attributes should be considered, please provide additional information:

15. Please review and rank the following attributes for consideration in evaluating the Regulatory Acceptance criteria (from “1” being most preferred to “3” being least preferred):

___ Applicable Regulations in Place
___ Presence of Permitting System
___ Zoning Limitations

16. If additional attributes should be considered, please provide additional information:

17. Please select additional barriers that exist in preventing future development of future end of life municipal solid waste management planning. If additional barriers are not listed, please provide comments under “other.”

_________ Organizational Barriers such as problems for the local authority such as lack of planning, strategic direction, and management (including lack of training) and poor communication

_________Lack of regional support from local and regional governments, other governmental departments, etc.

_________Transportation challenges: such as having enough trucks and staff to move waste, appropriate transport routes for waste hauling, etc.

16. If additional barriers exist, please provide additional barriers which may exist in municipal solid waste planning:

____

Thank you for your participation in this survey.

Appendix D

Rubric for DecisionTogether$^{©}$ Elicitation

Letter to Participants

2301 Vanderbilt Place

PMB 351826

Nashville, TN 37235-1826

May 15, 2019

Dear Participant,

My name is Andrea Gardiner and I am Ph.D. candidate in Environmental Engineering at Vanderbilt University working with Dr. Hiba Baroud. As part of my doctoral dissertation, I am developing an integrated framework combining life cycle assessment (LCA) and Analytical Hierarchy Process (AHP) to evaluate Future End of Life Municipal Solid Waste Technologies. I have developed a web application to evaluate the preferences of criteria and alternatives for MSW management systems to implement in Middle Tennessee. Your input will be used to test the developed methodology and evaluate its ability to identify areas of agreement or disagreement.

The attached document will assist you evaluating the impacts for five criteria and three end of life waste management systems. Please review the two paged attachment thoroughly prior to completion of the evaluation. Additional information to aid in your evaluation will be provided within the web application. The web application is located at: decisiontogether.com

The process should take 15-30 minutes to complete. Part 1 of the evaluation involves completing pairwise comparisons of criteria. In Part 2, a pairwise evaluation of the attributes of each criterion will be completed. In Part 3, quantitative and qualitative information for completing a pairwise comparison of the alternatives with respect to the criteria will be provided within the web application for review.

Your participation in this study is completely voluntary and your participation and any personally identifying information will be held confidential. For this research, only your stakeholder designation and compiled responses will be published. The Vanderbilt University Institutional Review Board has approved this evaluation. Should you have any comments or questions, please feel free to contact me at andrea.r.gardiner@vanderbilt.edu or 805-886-1975.

Thanks for your time and participation. The information you provide is valued and important for this research.

Andrea Gardiner, PE
PhD Candidate
Department of Civil and Environmental Engineering
Vanderbilt University

Instructions for Completing the Evaluation of Criteria and Scenarios for End of Life Waste Management Systems

Introduction

This evaluation will support the research that Andrea Resch Gardiner is doing for her doctoral studies. The results will be published for academic purposes in her dissertation as well as scientific journals. This research investigates the integration of Life Cycle Assessment (LCA) and Analytical Hierarchy Process (AHP) to evaluate stakeholder prioritization for end of life waste management for municipal solid waste (MSW) in Middle Tennessee. The results will be used to evaluate areas of stakeholder consensus and disagreement.

Goal

The goal of this evaluation is to determine which end of life residential (MSW) management system should be implemented for Middle Tennessee communities. As the current regional landfill will close in 5-8 years, Middle Tennessee counties and cities are evaluating future alternatives for MSW management. To evaluate this goal, AHP will be used to compare criteria and scenarios against the goal to identify areas of consensus and disagreement between diverse stakeholders while using pairwise comparison.

Criteria and Scenarios

The criteria and attributes to be evaluated with respect to the goal are shown in Table 2.

Table 2: Criteria and Sub-criteria

Criteria	Attributes
Environmental	Impacts to water, air, and land
Economics	Capital investments, operations and maintenance, economic incentives for communities, property values around facility
Social Acceptance	Employment, location with respect to community, noise/odor, ease of removal and management of MSW
Technical Feasibility	Availability of land/land use, energy efficiency, distance from community/ transfer station, beneficial reuse/resource conservation, available infrastructure
Regulatory Acceptance	Applicable regulations, presence of permitting system, zoning limitations

Three MSW management scenarios will be evaluated with respect to the criteria. The system boundaries encompass residential curbside pickup, management of waste at transfer station, transport to end of life management facility, operation at end of life waste management facility, as well as long term management at the facility. The scenarios assume that the distance to transfer stations and to the end of life waste management facility are equal for all scenarios. The scenarios considered in the evaluation include:

1. Scenario 1: Class I Landfill Facility
2. Scenario 2: Waste to energy facility with associated landfill and
3. Scenario 3: MSW composting facility with associated landfill

Elicitation Process

The elicitation process is completed using a web based application which guides stakeholders through a series of questions to first evaluate the criteria with respect to the goal and next the scenarios with respect to the criteria. The stakeholder will evaluate the relative importance of one criteria or scenario with another. This technique is referred to as pairwise comparison. Judgement will be made using the verbal/numerical and scale shown below:

Table 3: Pairwise Numerical and Verbal Scales

Level of Importance	Definition	Explanation
1	Equal Importance	Two criteria/alternatives contribute equally to the objective
2	Weak or Slight	
3	Moderate Importance	Experience and judgement slightly favor one criterion/alternative over another
4	Moderate Plus	
5	Strong Importance	Experience and judgement strongly favor one criterion/alternative over another
6	Strong Plus	
7	Very Strong or Demonstrated Importance	A criterion/alternative is favored strongly over another; its dominance is demonstrated in practice
8	Very, very strong	

9	Extreme Importance	The evidence favoring one criterion/alternative over another is of the highest possible order of affirmation

Source: Saaty, 2008

Process to Complete Evaluation

1. Visit Website: Decisiontogether.com.
2. Input email address and sector of waste management industry.
    a. Complete Part 1 pairwise comparison to evaluate the criteria with respect to the goal: which criteria is considered more important when evaluating end of life residential MSW systems for Middle Tennessee? Select value to show the degree of preference between the criteria and attributes. This is done by sliding the scale towards the criteria where there is greater preference.
    b. Add comment to the comment box to provide information on the judgement that you provided. This action is highly encouraged.
    c. Steps a and b will be repeated until all pairwise comparisons are completed.
    d. Stakeholders can navigate back to previous questions to check your responses at any time
3. Complete Part 2 pairwise comparison to evaluate the attributes with respect to the criteria.
4. Complete Part 3 pairwise comparisons to evaluate the scenarios with respect to criteria in the same manner as presented above.

The following text and information will be used in the web application.

Page		Main Box	Left Box	Description	Right Box	Description
1	Welcome	Thank you for your participation in this elicitation. This evaluation will support the research that Andrea Resch Gardiner is doing for her doctoral studies. The results will be published for academic purposes in her dissertation as well as scientific journals. This research investigates the integration of Life Cycle Assessment (LCA) and Analytical Hierarchy Process (AHP) to evaluate stakeholder prioritization for end of life waste management for municipal solid waste (MSW) in Middle Tennessee. The results will be used to evaluate areas of stakeholder consensus and disagreement. The goal of this evaluation is to determine which end of life residential MSW management system should be implemented for Middle Tennessee communities. As the current regional landfill will close in 5-8 years, Middle Tennessee counties and cities are evaluating future alternatives for MSW management. To evaluate this goal, AHP will be used to compare criteria and scenarios against the goal to identify				

The following text and information will be used in the web application.						
Page		Main Box	Left Box	Description	Right Box	Description
		areas of consensus and disagreement between diverse stakeholders while using pairwise comparison. This elicitation consists of 3 parts. The first part will require the participant to use pairwise comparison to evaluate the developed criteria with respect to the question: which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee? Part Two involves the pairwise comparison of the attributes for each criterion to answer the same question as above. Part Three involves the pairwise comparison of three selected alternatives with respect to the criteria with respect to the questions: which end of life municipal solid waste system is most preferred? Pairwise comparison will involve sliding the scale towards the preferred option to the degree that the option is preferred. Refer to the 2 page handout for additional information on the pairwise numerical and				

The following text and information will be used in the web application.

Page		Main Box	Left Box	Description	Right Box	Description
		verbal scale. Answers can be reviewed by navigating back through the web application. Once the comparison is complete, there is an opportunity to provide comments on why the selection was made. Comments are encouraged to inform the research on the thoughts behind the provided judgments. Should you have any questions during your participation in this study, please contact Andrea Gardiner at andrea.r.gardiner@vanderbilt.edu.				
2						
3	Part 1: Criteria Pairwise Evaluation	For this portion of the elicitation, five criteria will be considered using pairwise comparison. The pairwise comparison will be made with respect to the following question: which criteria is considered more important when evaluating end of life residential MSW systems for Middle Tennessee? The five criteria include:				

The following text and information will be used in the web application.						
Page		Main Box	Left Box	Description	Right Box	Description
		1. Environmental 2. Economics 3. Social Acceptance 4. Technical Feasibility 5. Regulatory Acceptance Upon completing each pairwise comparison, the participant is encouraged to provide comments in the comment box to give additional insight to researchers on the reasons the pairwise selection was made. At any time during the elicitation, the participant may review previously answered questions by selecting a previous question.				

The following text and information will be used in the web application.

Page		Main Box	Left Box	Description	Right Box	Description
4	Of the two criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee?	Environmental	The Environmental Criteria involves the potential environmental impacts to air, water and land as a result from an MSW management system. The environmental impacts are based on the emissions from daily and long term facility operations. The attributes include impacts to air, water and land. Potential air impacts include potential emissions such as methane,	Economics	The Economics Criteria involves the financial elements involved with the short and long term operations of the MSW management system. The attributes of the criteria include capital investments, operations and maintenance costs necessary for day to day operations of the facility and infrastructure, economic incentives that may be provide to communities located in the vicinity of the facility, and property values of land located around the facility.	Comment Box

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Page		Main Box	Left Box	Description	Right Box	Description
			global warming potential emissions (carbon dioxide - fossil, methane, nitrogen oxides, sulfur oxides, ammonia (air), hydrochloric acid), lead, particulate matter, inorganics, etc. Potential water impacts include inorganics, biological oxygen demand (BOD), chemical oxygen demand (COD), ammonia, and phosphate. Water impacts may affect both surface water			

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Page		Main Box	Left Box	Description	Right Box	Description
			and groundwater. Land impacts include elements which can affect the potential future land use and development, such as long term onsite disposal or impacts that cause contamination to surface and subsurface soils.			
5	Of the two criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee?	Environmental	The Environmental Criteria involves the potential environmental impacts to air, water and land as a result from an MSW management	Social Acceptance	The Social Acceptance Criteria involves the impact that a facility may have on a community. Attributes of Social Acceptance include:	Comment Box

The following text and information will be used in the web application.

Page		Main Box	Left Box	Description	Right Box	Description
			system. The environmental impacts are based on the emissions from daily and long term facility operations. The attributes include impacts to air, water and land. Potential air impacts include potential emissions such as methane, global warming potential emissions (carbon dioxide - fossil, methane, nitrogen oxides, sulfur oxides, ammonia (air), hydrochloric acid),		employment, location within community, noise/odor, and ease of removal and management of MSW. Employment includes the potential for long term jobs for community members. Location within the community involves the proximity of the facility to residential areas, whether urban or rural. Noise/odor involves the potential nuisances that can occur from facility operation that may impact residents living in the vicinity of the facility. Ease of	

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Page		Main Box	Left Box	Description	Right Box	Description
			lead, particulate matter, inorganics, etc. Potential water impacts include inorganics, biological oxygen demand (BOD), chemical oxygen demand (COD), ammonia, and phosphate. Water impacts may affect both surface water and groundwater. Land impacts include elements which can affect the potential future land use and development, such as long term onsite		removal and management of MSW involves the ability of the scenario to managed MSW in such a way that it does not impact the community's ability to have MSW managed in terms of current MSW operations.	

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			disposal or impacts that cause contamination to surface and subsurface soils.			
6	Of the two criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee?	Environmental	The Environmental Criteria involves the potential environmental impacts to air, water and land as a result from an MSW management system. The environmental impacts are based on the emissions from daily and long term facility operations. The attributes include	Technical Feasibility	The Technical Feasibility Criteria considers of several attributes such as the availability of land/land use, energy efficiency, distance from community/ transfer station, beneficial reuse/resource conservation, and available infrastructure. The availability of land and the current use of land is considered during siting and	Comment Box

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Page		Main Box	Left Box	Description	Right Box	Description
			impacts to air, water and land. Potential air impacts include potential emissions such as methane, global warming potential emissions (carbon dioxide - fossil, methane, nitrogen oxides, sulfur oxides, ammonia (air), hydrochloric acid), lead, particulate matter, inorganics, etc. Potential water impacts include inorganics, biological oxygen demand (BOD), chemical oxygen		operation of the facility. After the facility ceases operations, future land use needs to be considered. Energy efficiency involves the net gain or loss of energy during short and long term operations. In order to site a facility, factors must be considered such as its distance from the community it will service and its distance from the transfer station to ensure that transportation options are available. In addition, there must be consideration of	

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Page		Main Box	Left Box	Description	Right Box	Description
			demand (COD), ammonia, and phosphate. Water impacts may affect both surface water and groundwater. Land impacts include elements which can affect the potential future land use and development, such as long term onsite disposal or impacts that cause contamination to surface and subsurface soils.		available infrastructure such as electrical connections, roads, structures, etc. necessary to operate the facility.	
7	Of the two criteria being evaluated, which is considered more important when evaluating end of life	Environmental	The Environmental Criteria involves the potential	Regulatory Acceptance	The Regulatory Acceptance criteria considers the ability for	Comment Box

The following text and information will be used in the web application.						
Page		Main Box	Left Box	Description	Right Box	Description
	residential MSW systems for Middle Tennessee?		environmental impacts to air, water and land as a result from an MSW management system. The environmental impacts are based on the emissions from daily and long term facility operations. The attributes include impacts to air, water and land. Potential air impacts include potential emissions such as methane, global warming potential emissions (carbon dioxide -		a facility to be sited in the state, county, and city. Attributes of this criteria include applicable regulations, presence of permitting system, and zoning limitations. Applicable regulations refer to the existence of current regulations appropriate for permitting the facility. The presence of a permitting system refers to the existence of a regulatory authority and process which can review engineering plans and permitting documents to allow for the issuing of permits.	

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Page		Main Box	Left Box	Description	Right Box	Description
			fossil, methane, nitrogen oxides, sulfur oxides, ammonia (air), hydrochloric acid), lead, particulate matter, inorganics, etc. Potential water impacts include inorganics, biological oxygen demand (BOD), chemical oxygen demand (COD), ammonia, and phosphate. Water impacts may affect both surface water and groundwater. Land impacts include elements		Zoning limitations refer to the ability to site a facility without being hindered by zoning approval processes such as the Jackson Law.	

The following text and information will be used in the web application.

Page		Main Box	Left Box	Description	Right Box	Description
			which can affect the potential future land use and development, such as long term onsite disposal or impacts that cause contamination to surface and subsurface soils.			
8	Of the two criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee?	Economics	The Economics Criteria involves the financial elements involved with the short and long term operations of the MSW management system. The attributes of the criteria include capital investments,	Social Acceptance	The Social Acceptance Criteria involves the impact that a facility may have on a community. Attributes of Social Acceptance include: employment, location within community, noise/odor, and ease of removal and	

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Page		Main Box	Left Box	Description	Right Box	Description
			operations and maintenance costs necessary for day to day operations of the facility and infrastructure, economic incentives that may be provide to communities located in the vicinity of the facility, and property values of land located around the facility.		management of MSW. Employment includes the potential for long term jobs for community members. Location within the community involves the proximity of the facility to residential areas, whether urban or rural. Noise/odor involves the potential nuisances that can occur from facility operation that may impact residents living in the vicinity of the facility. Ease of removal and management of MSW involves the ability of the scenario to managed	

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Page		Main Box	Left Box	Description	Right Box	Description
					MSW in such a way that it does not impact the community's ability to have MSW managed in terms of current MSW operations.	
9	Of the two criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee?	Economics	The Economics Criteria involves the financial elements involved with the short and long term operations of the MSW management system. The attributes of the criteria include capital investments, operations and maintenance costs necessary for day to	Technical Feasibility	The Technical Feasibility Criteria considers of several attributes such as the availability of land/land use, energy efficiency, distance from community/ transfer station, beneficial reuse/resource conservation, and available infrastructure. The availability of land and the current use of	Comment Box

The following text and information will be used in the web application.						
Page		Main Box	Left Box	Description	Right Box	Description
			day operations of the facility and infrastructure, economic incentives that may be provide to communities located in the vicinity of the facility, and property values of land located around the facility.		land is considered during siting and operation of the facility. After the facility ceases operations, future land use needs to be considered. Energy efficiency involves the net gain or loss of energy during short and long term operations. In order to site a facility, factors must be considered such as its distance from the community it will service and its distance from the transfer station to ensure that transportation options are available. In	

The following text and information will be used in the web application.

Page		Main Box	Left Box	Description	Right Box	Description
					addition, there must be consideration of available infrastructure such as electrical connections, roads, structures, etc. necessary to operate the facility.	
10	Of the two criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee?	Economics	The Economics Criteria involves the financial elements involved with the short and long term operations of the MSW management system. The attributes of the criteria include capital investments, operations and maintenance costs	Regulatory Acceptance	The Regulatory Acceptance criteria considers the ability for a facility to be sited in the state, county, and city. Attributes of this criteria include applicable regulations, presence of permitting system, and zoning limitations. Applicable regulations refer to the existence of current	Comment Box

The following text and information will be used in the web application.

Page		Main Box	Left Box	Description	Right Box	Description
			necessary for day to day operations of the facility and infrastructure, economic incentives that may be provide to communities located in the vicinity of the facility, and property values of land located around the facility.		regulations appropriate for permitting the facility. The presence of a permitting system refers to the existence of a regulatory authority and process which can review engineering plans and permitting documents to allow for the issuing of permits. Zoning limitations refer to the ability to site a facility without being hindered by zoning approval processes such as the Jackson Law.	
11	Of the two criteria being evaluated, which is considered more important when evaluating end of life	Social Acceptance	The Social Acceptance Criteria involves the impact that a facility may	Technical Feasibility	The Technical Feasibility Criteria considers of several attributes such as the	Comment Box

The following text and information will be used in the web application.						
Page		Main Box	Left Box	Description	Right Box	Description
	residential MSW systems for Middle Tennessee?		have on a community. Attributes of Social Acceptance include: employment, location within community, noise/odor, and ease of removal and management of MSW. Employment includes the potential for long term jobs for community members. Location within the community involves the proximity of the facility to residential areas, whether urban		availability of land/land use, energy efficiency, distance from community/ transfer station, beneficial reuse/resource conservation, and available infrastructure. The availability of land and the current use of land is considered during siting and operation of the facility. After the facility ceases operations, future land use needs to be considered. Energy efficiency involves the net gain or loss of energy during short and long term operations.	

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Page		Main Box	Left Box	Description	Right Box	Description
			or rural. Noise/odor involves the potential nuisances that can occur from facility operation that may impact residents living in the vicinity of the facility. Ease of removal and management of MSW involves the ability of the scenario to managed MSW in such a way that it does not impact the community's ability to have MSW managed in terms of		In order to site a facility, factors must be considered such as its distance from the community it will service and its distance from the transfer station to ensure that transportation options are available. In addition, there must be consideration of available infrastructure such as electrical connections, roads, structures, etc. necessary to operate the facility.	

The following text and information will be used in the web application.

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			current MSW operations.			
12	Of the two criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee?	Social Acceptance	The Social Acceptance Criteria involves the impact that a facility may have on a community. Attributes of Social Acceptance include: employment, location within community, noise/odor, and ease of removal and management of MSW. Employment includes the potential for long term jobs for	Regulatory Acceptance	The Regulatory Acceptance criteria considers the ability for a facility to be sited in the state, county, and city. Attributes of this criteria include applicable regulations, presence of permitting system, and zoning limitations. Applicable regulations refer to the existence of current regulations appropriate for permitting the facility. The presence of a permitting system refers to the existence	Comment Box

The following text and information will be used in the web application.

Page		Main Box	Left Box	Description	Right Box	Description
			community members. Location within the community involves the proximity of the facility to residential areas, whether urban or rural. Noise/odor involves the potential nuisances that can occur from facility operation that may impact residents living in the vicinity of the facility. Ease of removal and management of MSW involves the ability of the scenario to managed		of a regulatory authority and process which can review engineering plans and permitting documents to allow for the issuing of permits. Zoning limitations refer to the ability to site a facility without being hindered by zoning approval processes such as the Jackson Law.	

The following text and information will be used in the web application.

Page		Main Box	Left Box	Description	Right Box	Description
			MSW in such a way that it does not impact the community's ability to have MSW managed in terms of current MSW operations.			
13	Of the two criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee?	Technical Feasibility	The Technical Feasibility Criteria considers of several attributes such as the availability of land/land use, energy efficiency, distance from community/ transfer station, beneficial reuse/resource conservation, and	Regulatory Acceptance	The Regulatory Acceptance criteria considers the ability for a facility to be sited in the state, county, and city. Attributes of this criteria include applicable regulations, presence of permitting system, and zoning limitations. Applicable regulations refer to the	Comment Box

The following text and information will be used in the web application.						
Page		Main Box	Left Box	Description	Right Box	Description
			available infrastructure. The availability of land and the current use of land is considered during siting and operation of the facility. After the facility ceases operations, future land use needs to be considered. Energy efficiency involves the net gain or loss of energy during short and long term operations. In order to site a facility, factors must be considered such as its distance from the		existence of current regulations appropriate for permitting the facility. The presence of a permitting system refers to the existence of a regulatory authority and process which can review engineering plans and permitting documents to allow for the issuing of permits. Zoning limitations refer to the ability to site a facility without being hindered by zoning approval processes such as the Jackson Law.	

The following text and information will be used in the web application.						
Page		Main Box	Left Box	Description	Right Box	Description
			community it will service and its distance from the transfer station to ensure that transportation options are available. In addition, there must be consideration of available infrastructure such as electrical connections, roads, structures, etc. necessary to operate the facility.			
14	Part 2: Attribute Pairwise Evaluation	For this portion of the evaluation, the attributes of the five criteria will be evaluated using pairwise comparison. This process will aid in providing understanding on the prioritization of the attributes				

The following text and information will be used in the web application.						
Page		Main Box	Left Box	Description	Right Box	Description
		with respect to evaluation of end of life MSW systems. The pairwise comparison will be made with respect to the following question: which attribute is considered more important when evaluating the criteria for considering MSW systems for Middle Tennessee? The attributes of the five criteria include: 1. Environmental: a. Impacts to air b. Impacts to water c. Impacts to land 2. Economics a. Capital investments b. Operations and maintenance c. Economic incentives for communities d. Property values around facility 3. Social Acceptance a. Employment b. Noise/odor c. Ease of removal and management of MSW 4. Technical Feasibility a. Availability of land/land use b. Energy efficiency c. Distance from community/transfer station d. Beneficial reuse/resource conservation e. Available infrastructure 5. Regulatory Acceptance a. Applicable regulations b. Presence of permitting system c. Zoning limitations				

The following text and information will be used in the web application.						
Page		Main Box	Left Box	Description	Right Box	Description
		Upon completing each pairwise comparison, the participant is encouraged to provide comments in the provided comment box to provide additional insight to the reasons the pairwise selection was made. At any time during the elicitation, the participant may review previously answered questions by selecting a previous question.				
15	Of the attributes of the Environmental Criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee?	Impacts to air	Impacts to air		Impacts to water	
16	Of the attributes of the Environmental Criteria being evaluated, which is considered more important when evaluating end of	Impacts to air	Impacts to air		Impacts to land	

The following text and information will be used in the web application.

Page		Main Box	Left Box	Description	Right Box	Description
	life residential MSW systems for Middle Tennessee?					
17	Of the attributes of the Environmental Criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee?	Impacts to water	Impacts to water		Impacts to land	
18	Of the attributes of the Economics Criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee?		Capital investments		Operations and maintenance	
19	Of the attributes of the Economics Criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee?		Capital investments		Economic incentives for communities	

The following text and information will be used in the web application.

Page		Main Box	Left Box	Description	Right Box	Description
20	Of the attributes of the Economics Criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee?		Capital investments		Property values around facility	
21	Of the attributes of the Economics Criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee?		Operations and maintenance		Economic incentives for communities	
22	Of the attributes of the Economics Criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee?		Operations and maintenance		Property values around facility	
23	Of the attributes of the Economics Criteria being evaluated, which is considered more important when		Economic incentives for communities		Property values around facility	

The following text and information will be used in the web application.

Page		Main Box	Left Box	Description	Right Box	Description
	evaluating end of life residential MSW systems for Middle Tennessee?					
24	Of the attributes of the Social Acceptance Criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee?		Employment		Noise/odor	
25	Of the attributes of the Social Acceptance Criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee?		Employment		Ease of removal and management of MSW	
26			Employment		Location with respect to community	
27	Of the attributes of the Social Acceptance Criteria being evaluated, which is considered more important when evaluating end of life		Noise/odor		Ease of removal and management of MSW	

The following text and information will be used in the web application.

Page		Main Box	Left Box	Description	Right Box	Description
	residential MSW systems for Middle Tennessee?					
28	Of the attributes of the Social Acceptance Criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee?		Noise/odor		Location with respect to community	
29	Of the attributes of the Social Acceptance Criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee?		Ease of removal and management of MSW		Location with respect to community	
30	Of the attributes of the Technical Feasibility Criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee		Availability of land/land use		Energy efficiency	

The following text and information will be used in the web application.

Page		Main Box	Left Box	Description	Right Box	Description
31	Of the attributes of the Technical Feasibility Criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee		Availability of land/land use		Distance from community/transfer station	
32	Of the attributes of the Technical Feasibility Criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee		Availability of land/land use		Beneficial reuse/resource conservation	
33	Of the attributes of the Technical Feasibility Criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee		Availability of land/land use		Available infrastructure	
34	Of the attributes of the Technical Feasibility Criteria being evaluated, which is considered more important		Energy efficiency		Distance from community/transfer station	

The following text and information will be used in the web application.

Page		Main Box	Left Box	Description	Right Box	Description
	when evaluating end of life residential MSW systems for Middle Tennessee					
35	Of the attributes of the Technical Feasibility Criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee		Energy efficiency		Beneficial reuse/resource conservation	
36	Of the attributes of the Technical Feasibility Criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee		Energy efficiency		Available infrastructure	
37	Of the attributes of the Technical Feasibility Criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee		Distance from community/transfer station		Beneficial reuse/resource conservation	

The following text and information will be used in the web application.						
Page		Main Box	Left Box	Description	Right Box	Description
38	Of the attributes of the Technical Feasibility Criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee		Distance from community/transfer station		Available infrastructure	
39	Of the attributes of the Technical Feasibility Criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee		Beneficial reuse/resource conservation		Available infrastructure	
40	Of the attributes of the Regulatory Acceptance Criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee		Applicable regulations		Presence of permitting system	
41	Of the attributes of the Regulatory Acceptance Criteria being evaluated, which is considered more important		Applicable regulations		Zoning limitations	

The following text and information will be used in the web application.

Page		Main Box	Left Box	Description	Right Box	Description
	when evaluating end of life residential MSW systems for Middle Tennessee					
42	Of the attributes of the Regulatory Acceptance Criteria being evaluated, which is considered more important when evaluating end of life residential MSW systems for Middle Tennessee		Presence of permitting system		Zoning limitations	
43	Part 3: Scenario Pairwise Comparison	For this portion of the evaluation, three scenarios will be considered using pairwise comparison. The comparisons will be made based on the question: which end of life municipal solid waste system is most preferred? The three scenarios include: Scenario 1: Class I MSW landfill facility Scenario 2: Waste to energy facility with associated landfill Scenario 3: MSW composting facility with associated landfill				

The following text and information will be used in the web application.

Page		Main Box	Left Box	Description	Right Box	Description
		All scenarios assume that collection of MSW from residential locations utilize standard side and rear collection trucks. Once trucks are full, waste is transported to transfer station within the metropolitan area. At the transfer station, collection trucks dump MSW on the tipping floor. MSW is then loaded into trailers for transport to end of life management facility. The transfer facility is completely enclosed, and any leachate produced is pumped to a municipal wastewater treatment facility for additional treatment. Upon loading the MSW into trailers, it is transported by truck to the end of life management facility. It is assumed that the end of life management facility is located no more than 30 miles from the transfer station. Upon completing each pairwise comparison, the participant is encouraged to provide comments in the provided comment box to provide additional insight to the reasons the pairwise selection was made.				

The following text and information will be used in the web application.						
Page		Main Box	Left Box	Description	Right Box	Description
		At any time during the elicitation, the participant may review previously answered questions by selecting a previous question.				
44	Based on the Environmental Criterion, which end of life municipal solid waste system is most preferred?	Environmental	Scenario 1: Class I Municipal Solid Waste Landfill	This scenario involves MSW being disposed of in a Class I Landfill. Once the MSW has arrived at the facility it is dumped from trailers onto to the landfill working face, where it is compacted and covered per regulations. Operations include the management of leachate and landfill gas, as well as placement of daily and intermediate, as well as	Scenario 2: Waste to Energy Facility with Associated Landfill	This scenario involves MSW being processed in a waste to energy facility to produce steam and electricity. MSW is brought to the facility where it is processed and sorted prior to incineration. The facility produces steam and electricity for use. Residual, non-combustible material, and ash is disposed at an onsite permitted landfill. Upon closure

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Page		Main Box	Left Box	Description	Right Box	Description
				long term closure of the waste areas as necessary. Upon closure of the facility, long term management includes the collection of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing structures such as collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period.		of the facility, long term management includes the collection of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing structures such as gas/leachate collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period

The following text and information will be used in the web application.						
Page		Main Box	Left Box	Description	Right Box	Description
45	Based on the Environmental Criterion, which end of life municipal solid waste system is most preferred?	Environmental	Scenario 1: Class I Municipal Solid Waste Landfill	This scenario involves MSW being disposed of in a Class I Landfill. Once the MSW has arrived at the facility it is dumped from trailers onto to the landfill working face, where it is compacted and covered per regulations. Operations include the management of leachate and landfill gas, as well as placement of daily and intermediate, as well as long term closure of the waste areas as necessary. Upon closure of the facility, long term management	Scenario 3: Municipal Solid Waste Composting with Associated Landfill	This scenario involves MSW being processed in an MSW composting facility, where is processed, separated and composted. Residual, non-combustible materials are disposed at an onsite permitted landfill. Upon closure of the facility, long term management includes the collection of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing structures such as

The following text and information will be used in the web application.

Page		Main Box	Left Box	Description	Right Box	Description
				includes the collection of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing structures such as collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period.		collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period.
46	Based on the Environmental Criterion, which end of life municipal solid waste system is most preferred?	Environmental	Scenario 2: Waste to Energy Facility with Associated Landfill		Scenario 3: Municipal Solid Waste Composting with Associated Landfill	This scenario involves MSW being processed in an MSW composting facility, where is processed, separated and composted. Residual, non-

The following text and information will be used in the web application.						
Page		Main Box	Left Box	Description	Right Box	Description
						combustible materials are disposed at an onsite permitted landfill. Upon closure of the facility, long term management includes the collection of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing structures such as collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period.

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Page		Main Box	Left Box	Description	Right Box	Description
47	Based on the Economics Criterion, which end of life municipal solid waste system is most preferred?	Economics	Scenario 1: Class I Municipal Solid Waste Landfill	This scenario involves MSW being disposed of in a Class I Landfill. Once the MSW has arrived at the facility it is dumped from trailers onto to the landfill working face, where it is compacted and covered per regulations. Operations include the management of leachate and landfill gas, as well as placement of daily and intermediate, as well as long term closure of the waste areas as necessary. Upon closure of the facility, long term management	Scenario 2: Waste to Energy Facility with Associated Landfill	This scenario involves MSW being processed in a waste to energy facility to produce steam and electricity. MSW is brought to the facility where it is processed and sorted prior to incineration. The facility produces steam and electricity for use. Residual, non-combustible material, and ash is disposed at an onsite permitted landfill. Upon closure of the facility, long term management includes the collection of landfill leachate and gas per regulatory

The following text and information will be used in the web application.

Page		Main Box	Left Box	Description	Right Box	Description
				includes the collection of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing structures such as collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period.		requirements. This also includes maintenance of the facility to maintain existing structures such as gas/leachate collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period,
48	Based on the Economics Criterion, which end of life municipal solid waste system is most preferred?	Economics	Scenario 1: Class I Municipal Solid Waste Landfill	This scenario involves MSW being disposed of in a Class I Landfill. Once the MSW has arrived at the facility it is dumped from trailers onto to the landfill	Scenario 3: Municipal Solid Waste Composting with Associated Landfill	This scenario involves MSW being processed in an MSW composting facility, where is processed, separated and composted. Residual, non-

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Page		Main Box	Left Box	Description	Right Box	Description
				working face, where it is compacted and covered per regulations. Operations include the management of leachate and landfill gas, as well as placement of daily and intermediate, as well as long term closure of the waste areas as necessary. Upon closure of the facility, long term management includes the collection of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing		combustible materials are disposed at an onsite permitted landfill. Upon closure of the facility, long term management includes the collection of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing structures such as collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period.

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Page		Main Box	Left Box	Description	Right Box	Description
				structures such as collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period.		
49	Based on the Economics Criterion, which end of life municipal solid waste system is most preferred?	Economics	Scenario 2: Waste to Energy Facility with Associated Landfill		Scenario 3: Municipal Solid Waste Composting with Associated Landfill	This scenario involves MSW being processed in an MSW composting facility, where is processed, separated and composted. Residual, non-combustible materials are disposed at an onsite permitted landfill. Upon closure of the facility, long term management includes the collection

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Page		Main Box	Left Box	Description	Right Box	Description
						of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing structures such as collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period.
50	Based on the Social Acceptance Criterion, which end of life municipal solid waste system is most preferred?	Social Acceptance	Scenario 1: Class I Municipal Solid Waste Landfill	This scenario involves MSW being disposed of in a Class I Landfill. Once the MSW has arrived at the facility it is dumped from trailers onto to the landfill working face, where it	Scenario 2: Waste to Energy Facility with Associated Landfill	This scenario involves MSW being processed in a waste to energy facility to produce steam and electricity. MSW is brought to the facility where it is processed and sorted

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Page		Main Box	Left Box	Description	Right Box	Description
				is compacted and covered per regulations. Operations include the management of leachate and landfill gas, as well as placement of daily and intermediate, as well as long term closure of the waste areas as necessary. Upon closure of the facility, long term management includes the collection of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing structures such as		prior to incineration. The facility produces steam and electricity for use. Residual, non-combustible material, and ash is disposed at an onsite permitted landfill. Upon closure of the facility, long term management includes the collection of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing structures such as gas/leachate collection systems and cap/cover. It is assumed that the

The following text and information will be used in the web application.

Page		Main Box	Left Box	Description	Right Box	Description
				collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period.		landfill has a minimum 20-year post closure period.
51	Based on the Social Acceptance Criterion, which end of life municipal solid waste system is most preferred?	Social Acceptance	Scenario 1: Class I Municipal Solid Waste Landfill	This scenario involves MSW being disposed of in a Class I Landfill. Once the MSW has arrived at the facility it is dumped from trailers onto to the landfill working face, where it is compacted and covered per regulations. Operations include the management of leachate and landfill gas, as well as placement of daily and	Scenario 3: Municipal Solid Waste Composting with Associated Landfill	This scenario involves MSW being processed in an MSW composting facility, where is processed, separated and composted. Residual, non-combustible materials are disposed at an onsite permitted landfill. Upon closure of the facility, long term management includes the collection of landfill leachate and

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Page		Main Box	Left Box	Description	Right Box	Description
				intermediate, as well as long term closure of the waste areas as necessary. Upon closure of the facility, long term management includes the collection of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing structures such as collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period.		gas per regulatory requirements. This also includes maintenance of the facility to maintain existing structures such as collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period.

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Page		Main Box	Left Box	Description	Right Box	Description
52	Based on the Social Acceptance Criterion, which end of life municipal solid waste system is most preferred?	Social Acceptance	Scenario 2: Waste to Energy Facility with Associated Landfill		Scenario 3: Municipal Solid Waste Composting with Associated Landfill	This scenario involves MSW being processed in an MSW composting facility, where is processed, separated and composted. Residual, non-combustible materials are disposed at an onsite permitted landfill. Upon closure of the facility, long term management includes the collection of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing structures such as

The following text and information will be used in the web application.

Page		Main Box	Left Box	Description	Right Box	Description
						collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period.
53	Based on the Technical Feasibility Criterion, which end of life municipal solid waste system is most preferred?	Technical Feasibility	Scenario 1: Class I Municipal Solid Waste Landfill	This scenario involves MSW being disposed of in a Class I Landfill. Once the MSW has arrived at the facility it is dumped from trailers onto to the landfill working face, where it is compacted and covered per regulations. Operations include the management of leachate and landfill gas, as well as placement of daily and	Scenario 2: Waste to Energy Facility with Associated Landfill	This scenario involves MSW being processed in a waste to energy facility to produce steam and electricity. MSW is brought to the facility where it is processed and sorted prior to incineration. The facility produces steam and electricity for use. Residual, non-combustible material, and ash is disposed at an onsite permitted

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Page		Main Box	Left Box	Description	Right Box	Description
				intermediate, as well as long term closure of the waste areas as necessary. Upon closure of the facility, long term management includes the collection of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing structures such as collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period.		landfill. Upon closure of the facility, long term management includes the collection of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing structures such as gas/leachate collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period.

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Page		Main Box	Left Box	Description	Right Box	Description
54	Based on the Technical Feasibility Criterion, which end of life municipal solid waste system is most preferred?	Technical Feasibility	Scenario 1: Class I Municipal Solid Waste Landfill	This scenario involves MSW being disposed of in a Class I Landfill. Once the MSW has arrived at the facility it is dumped from trailers onto to the landfill working face, where it is compacted and covered per regulations. Operations include the management of leachate and landfill gas, as well as placement of daily and intermediate, as well as long term closure of the waste areas as necessary. Upon closure of the facility, long term management	Scenario 3: Municipal Solid Waste Composting with Associated Landfill	This scenario involves MSW being processed in an MSW composting facility, where is processed, separated and composted. Residual, non-combustible materials are disposed at an onsite permitted landfill. Upon closure of the facility, long term management includes the collection of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing structures such as

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Page		Main Box	Left Box	Description	Right Box	Description
				includes the collection of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing structures such as collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period.		collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period.
55	Based on the Technical Feasibility Criterion, which end of life municipal solid waste system is most preferred?	Technical Feasibility	Scenario 2: Waste to Energy Facility with Associated Landfill		Scenario 3: Municipal Solid Waste Composting with Associated Landfill	This scenario involves MSW being processed in an MSW composting facility, where is processed, separated and composted. Residual, non-

The following text and information will be used in the web application.						
Page		Main Box	Left Box	Description	Right Box	Description
						combustible materials are disposed at an onsite permitted landfill. Upon closure of the facility, long term management includes the collection of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing structures such as collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period.

The following text and information will be used in the web application.

Page		Main Box	Left Box	Description	Right Box	Description
56	Based on the Regulatory Acceptance, which end of life municipal solid waste system is most preferred?	Regulatory Acceptance	Scenario 1: Class I Municipal Solid Waste Landfill	This scenario involves MSW being disposed of in a Class I Landfill. Once the MSW has arrived at the facility it is dumped from trailers onto to the landfill working face, where it is compacted and covered per regulations. Operations include the management of leachate and landfill gas, as well as placement of daily and intermediate, as well as long term closure of the waste areas as necessary. Upon closure of the facility, long term management	Scenario 2: Waste to Energy Facility with Associated Landfill	This scenario involves MSW being processed in a waste to energy facility to produce steam and electricity. MSW is brought to the facility where it is processed and sorted prior to incineration. The facility produces steam and electricity for use. Residual, non-combustible material, and ash is disposed at an onsite permitted landfill. Upon closure of the facility, long term management includes the collection of landfill leachate and gas per regulatory

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Page		Main Box	Left Box	Description	Right Box	Description
				includes the collection of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing structures such as collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period.		requirements. This also includes maintenance of the facility to maintain existing structures such as gas/leachate collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period.
57	Based on the Regulatory Acceptance, which end of life municipal solid waste system is most preferred?	Regulatory Acceptance	Scenario 1: Class I Municipal Solid Waste Landfill	This scenario involves MSW being disposed of in a Class I Landfill. Once the MSW has arrived at the facility it is dumped from trailers onto to the landfill	Scenario 3: Municipal Solid Waste Composting with Associated Landfill	This scenario involves MSW being processed in an MSW composting facility, where is processed, separated and composted. Residual, non-

The following text and information will be used in the web application.

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				working face, where it is compacted and covered per regulations. Operations include the management of leachate and landfill gas, as well as placement of daily and intermediate, as well as long term closure of the waste areas as necessary. Upon closure of the facility, long term management includes the collection of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing		combustible materials are disposed at an onsite permitted landfill. Upon closure of the facility, long term management includes the collection of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing structures such as collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period.

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Page		Main Box	Left Box	Description	Right Box	Description
				structures such as collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period.		
58	Based on the Regulatory Acceptance, which end of life municipal solid waste system is most preferred?	Regulatory Acceptance	Scenario 2: Waste to Energy Facility with Associated Landfill		Scenario 3: Municipal Solid Waste Composting with Associated Landfill	This scenario involves MSW being processed in an MSW composting facility, where is processed, separated and composted. Residual, non-combustible materials are disposed at an onsite permitted landfill. Upon closure of the facility, long term management includes the collection

The following text and information will be used in the web application.

Page		Main Box	Left Box	Description	Right Box	Description
						of landfill leachate and gas per regulatory requirements. This also includes maintenance of the facility to maintain existing structures such as collection systems and cap/cover. It is assumed that the landfill has a minimum 20-year post closure period.
59	Thank you for your time to complete this elicitation for my PhD Dissertation. Your time and input are greatly appreciated.					

Appendix E

Results of DecisionTogether$^{©}$ Elicitation

Consistency Index and Consistency Ratio for Group 1: SWA, CG, and CLM

User	Evaluation	Consistency Index	Consistency Ratio	Consistency Ratio Percentage
SWA 1	Part 1	0.37	0.33	33
	Part 2 - Environmental	0.00	0.00	0
	Part 2 - Economics	0.05	0.06	6
	Part 2 - Social Acceptance	0.01	0.02	2
	Part 2 - Technical Feasibility	0.03	0.03	3
	Part 2 - Regulatory Acceptance	0.00	0.00	0
	Part 3 - Environmental	0.04	0.07	7
	Part 3 - Economics	0.05	0.08	8
	Part 3 - Social Acceptance	0.00	0.00	0
	Part 3 - Technical Feasibility	0.00	0.01	1
	Part 3 - Regulatory Acceptance	0.03	0.05	5
SWA 2	Part 1	0.045	0.040	4
	Part 2 - Environmental	0.000	0.000	0
	Part 2 - Economics	0.239	0.265	27
	Part 2 - Social Acceptance	0.110	0.189	19
	Part 2 - Technical Feasibility	0.128	0.115	11
	Part 2 - Regulatory Acceptance	0.000	0.000	0
	Part 3 - Environmental	0.000	0.000	0
	Part 3 - Economics	0.154	0.265	27
	Part 3 - Social Acceptance	0.069	0.119	12
	Part 3 - Technical Feasibility	0.069	0.120	12
	Part 3 - Regulatory Acceptance	0.037	0.064	6
SWA 3	Part 1	0.060	0.053	5
	Part 2 - Environmental	0.000	0.000	0
	Part 2 - Economics	0.020	0.023	2
	Part 2 - Social Acceptance	0.027	0.046	5
	Part 2 - Technical Feasibility	0.034	0.030	3
	Part 2 - Regulatory Acceptance	0.027	0.046	5
	Part 3 - Environmental	0.000	0.000	0
	Part 3 - Economics	0.000	0.000	0
	Part 3 - Social Acceptance	0.000	0.000	0
	Part 3 - Technical Feasibility	0.000	0.000	0
	Part 3 - Regulatory Acceptance	0.027	0.046	5
CG 1	Part 1	0.468	0.418	42
	Part 2 - Environmental	0.068	0.117	12
	Part 2 - Economics	0.000	0.000	0
	Part 2 - Social Acceptance	0.069	0.119	12

Consistency Index and Consistency Ratio for Group 1: SWA, CG, and CLM

User	Evaluation	Consistency Index	Consistency Ratio	Consistency Ratio Percentage
	Part 2 - Technical Feasibility	0.186	0.166	17
	Part 2 - Regulatory Acceptance	0.000	0.000	0
	Part 3 - Environmental	0.027	0.047	5
	Part 3 - Economics	0.147	0.253	25
	Part 3 - Social Acceptance	0.009	0.016	2
	Part 3 - Technical Feasibility	0.068	0.117	12
	Part 3 - Regulatory Acceptance	0.000	0.000	0
CG 2	Part 1	0.100	0.090	9
	Part 2 - Environmental	0.000	0.000	0
	Part 2 - Economics	0.048	0.054	5
	Part 2 - Social Acceptance	0.003	0.005	0
	Part 2 - Technical Feasibility	0.044	0.040	4
	Part 2 - Regulatory Acceptance	0.009	0.016	2
	Part 3 - Environmental	0.001	0.002	0
	Part 3 - Economics	0.000	0.000	0
	Part 3 - Social Acceptance	0.001	0.002	0
	Part 3 - Technical Feasibility	0.000	0.000	0
	Part 3 - Regulatory Acceptance	0.069	0.118	12
CLM 1	Part 1	0.402	0.359	36
	Part 2 - Environmental	0.235	0.405	41
	Part 2 - Economics	0.215	0.239	24
	Part 2 - Social Acceptance	0.043	0.075	7
	Part 2 - Technical Feasibility	0.301	0.269	27
	Part 2 - Regulatory Acceptance	0.111	0.191	19
	Part 3 - Environmental	0.112	0.193	19
	Part 3 - Economics	0.193	0.333	33
	Part 3 - Social Acceptance	0.112	0.192	19
	Part 3 - Technical Feasibility	0.069	0.119	12
	Part 3 - Regulatory Acceptance	0.153	0.264	26
CLM 2	Part 1	0.100	0.090	9
	Part 2 - Environmental	0.130	0.225	22
	Part 2 - Economics	0.336	0.374	37
	Part 2 - Social Acceptance	0.151	0.260	26
	Part 2 - Technical Feasibility	0.151	0.135	14
	Part 2 - Regulatory Acceptance	0.002	0.003	0
	Part 3 - Environmental	0.154	0.265	27
	Part 3 - Economics	0.154	0.265	27
	Part 3 - Social Acceptance	0.069	0.120	12
	Part 3 - Technical Feasibility	0.154	0.265	27

Consistency Index and Consistency Ratio for Group 1: SWA, CG, and CLM

User	Evaluation	Consistency Index	Consistency Ratio	Consistency Ratio Percentage
	Part 3 - Regulatory Acceptance	0.069	0.120	12

Consistency Index and Consistency Ratio for Group 2: R and O

User	Evaluation	Consistency Index	Consistency Ratio	Consistency Ratio Percentage
R 1	Part 1	0.12	0.11	11
	Part 2 - Environmental	0.00	0.00	0
	Part 2 - Economics	0.00	0.00	0
	Part 2 - Social Acceptance	0.00	0.00	0
	Part 2 - Technical Feasibility	0.05	0.04	4
	Part 2 - Regulatory Acceptance	0.00	0.00	0
	Part 3 - Environmental	0.00	0.00	0
	Part 3 - Economics	0.03	0.05	5
	Part 3 - Social Acceptance	0.00	0.00	0
	Part 3 - Technical Feasibility	0.03	0.05	5
	Part 3 - Regulatory Acceptance	0.07	0.12	12
R 2	Part 1	0.14	0.12	12
	Part 2 - Environmental	0.16	0.27	27
	Part 2 - Economics	0.11	0.13	13
	Part 2 - Social Acceptance	0.45	0.77	77
	Part 2 - Technical Feasibility	0.16	0.14	14
	Part 2 - Regulatory Acceptance	0.07	0.12	12
	Part 3 - Environmental	0.07	0.12	12
	Part 3 - Economics	0.07	0.12	12
	Part 3 - Social Acceptance	0.07	0.12	12
	Part 3 - Technical Feasibility	0.04	0.07	7
	Part 3 - Regulatory Acceptance	0.00	0.01	1
R 3	Part 1	0.35	0.32	32
	Part 2 - Environmental	0.00	0.00	0
	Part 2 - Economics	0.05	0.06	6
	Part 2 - Social Acceptance	0.07	0.12	12
	Part 2 - Technical Feasibility	0.18	0.16	16
	Part 2 - Regulatory Acceptance	0.00	0.00	0
	Part 3 - Environmental	0.24	0.41	41
	Part 3 - Economics	0.24	0.41	41

Consistency Index and Consistency Ratio for Group 2: R and O				
User	Evaluation	Consistency Index	Consistency Ratio	Consistency Ratio Percentage
	Part 3 - Social Acceptance	0.24	0.41	41
	Part 3 - Technical Feasibility	0.24	0.41	41
	Part 3 - Regulatory Acceptance	0.24	0.41	41
R 4	Part 1	0.04	0.03	3
	Part 2 - Environmental	0.00	0.00	0
	Part 2 - Economics	0.05	0.06	6
	Part 2 - Social Acceptance	0.00	0.00	0
	Part 2 - Technical Feasibility	0.00	0.00	0
	Part 2 - Regulatory Acceptance	0.00	0.00	0
	Part 3 - Environmental	0.00	0.00	0
	Part 3 - Economics	0.07	0.12	12
	Part 3 - Social Acceptance	0.11	0.19	19
	Part 3 - Technical Feasibility	0.07	0.12	12
	Part 3 - Regulatory Acceptance	0.07	0.12	12
R 5	Part 1	0.22	0.20	20
	Part 2 - Environmental	0.04	0.07	7
	Part 2 - Economics	0.25	0.28	28
	Part 2 - Social Acceptance	0.12	0.21	21
	Part 2 - Technical Feasibility	0.25	0.22	22
	Part 2 - Regulatory Acceptance	0.11	0.19	19
	Part 3 - Environmental	0.23	0.40	40
	Part 3 - Economics	0.16	0.27	27
	Part 3 - Social Acceptance	0.03	0.06	6
	Part 3 - Technical Feasibility	0.15	0.27	27
	Part 3 - Regulatory Acceptance	0.00	0.00	0
R 6	Part 1	0.31	0.28	28
	Part 2 - Environmental	0.07	0.12	12
	Part 2 - Economics	0.04	0.04	4
	Part 2 - Social Acceptance	0.05	0.09	9
	Part 2 - Technical Feasibility	0.13	0.12	12
	Part 2 - Regulatory Acceptance	0.00	0.00	0
	Part 3 - Environmental	0.00	0.00	0
	Part 3 - Economics	0.03	0.05	5
	Part 3 - Social Acceptance	0.07	0.12	12
	Part 3 - Technical Feasibility	0.11	0.19	19
	Part 3 - Regulatory Acceptance	0.07	0.12	12
R 7	Part 1	0.14	0.13	13

Consistency Index and Consistency Ratio for Group 2: R and O

User	Evaluation	Consistency Index	Consistency Ratio	Consistency Ratio Percentage
	Part 2 - Environmental	0.15	0.27	27
	Part 2 - Economics	0.54	0.60	60
	Part 2 - Social Acceptance	0.07	0.12	12
	Part 2 - Technical Feasibility	0.34	0.30	30
	Part 2 - Regulatory Acceptance	0.11	0.19	19
	Part 3 - Environmental	0.07	0.12	12
	Part 3 - Economics	0.15	0.27	27
	Part 3 - Social Acceptance	0.15	0.27	27
	Part 3 - Technical Feasibility	0.11	0.19	19
	Part 3 - Regulatory Acceptance	0.11	0.19	19

Consistency Index and Consistency Ratio for Group 3: GP

User	Evaluation	Consistency Index	Consistency Ratio	Consistency Ratio Percentage
GP 1	Part 1	0.44	0.39	39
	Part 2 - Environmental	0.31	0.54	54
	Part 2 - Economics	0.50	0.56	56
	Part 2 - Social Acceptance	0.31	0.54	54
	Part 2 - Technical Feasibility	0.44	0.39	39
	Part 2 - Regulatory Acceptance	0.31	0.54	54
	Part 3 - Environmental	0.31	0.54	54
	Part 3 - Economics	0.31	0.54	54
	Part 3 - Social Acceptance	0.31	0.54	54
	Part 3 - Technical Feasibility	0.31	0.54	54
	Part 3 - Regulatory Acceptance	0.31	0.54	54
GP 2	Part 1	0.66	0.59	59
	Part 2 - Environmental	0.31	0.54	54
	Part 2 - Economics	0.52	0.58	58
	Part 2 - Social Acceptance	0.31	0.54	54
	Part 2 - Technical Feasibility	0.66	0.59	59
	Part 2 - Regulatory Acceptance	0.31	0.54	54
	Part 3 - Environmental	0.31	0.54	54
	Part 3 - Economics	0.31	0.54	54
	Part 3 - Social Acceptance	0.31	0.54	54
	Part 3 - Technical Feasibility	0.31	0.54	54
	Part 3 - Regulatory Acceptance	0.31	0.54	54
GP 3	Part 1+N53	0.29	0.26	26
	Part 2 - Environmental	0.19	0.33	33
	Part 2 - Economics	0.28	0.31	31
	Part 2 - Social Acceptance	0.47	0.81	81
	Part 2 - Technical Feasibility	0.92	0.82	82
	Part 2 - Regulatory Acceptance	0.33	0.57	57
	Part 3 - Environmental	0.20	0.35	35
	Part 3 - Economics	0.23	0.40	40
	Part 3 - Social Acceptance	0.20	0.34	34
	Part 3 - Technical Feasibility	0.19	0.32	32
	Part 3 - Regulatory Acceptance	0.23	0.40	40
GP 4	Part 1	0.59	0.53	53
	Part 2 - Environmental	0.00	0.00	0
	Part 2 - Economics	0.11	0.12	12

	Part 2 - Social Acceptance	0.07	0.12	12
	Part 2 - Technical Feasibility	0.13	0.11	11
	Part 2 - Regulatory Acceptance	0.07	0.12	12
	Part 3 - Environmental	0.07	0.12	12
	Part 3 - Economics	0.07	0.12	12
	Part 3 - Social Acceptance	0.07	0.12	12
	Part 3 - Technical Feasibility	0.07	0.12	12
	Part 3 - Regulatory Acceptance	0.07	0.12	12
GP 5	Part 1	0.18	0.16	16
	Part 2 - Environmental	0.00	0.00	0
	Part 2 - Economics	0.15	0.17	17
	Part 2 - Social Acceptance	0.15	0.26	26
	Part 2 - Technical Feasibility	0.00	0.00	0
	Part 2 - Regulatory Acceptance	0.00	0.00	0
	Part 3 - Environmental	0.00	0.00	0
	Part 3 - Economics	0.00	0.00	0
	Part 3 - Social Acceptance	0.00	0.00	0
	Part 3 - Technical Feasibility	0.00	0.00	0
	Part 3 - Regulatory Acceptance	0.00	0.00	0
GP 6	Part 1	0.20	0.18	18
	Part 2 - Environmental	0.00	0.00	0
	Part 2 - Economics	0.05	0.06	6
	Part 2 - Social Acceptance	0.00	0.00	0
	Part 2 - Technical Feasibility	0.13	0.12	12
	Part 2 - Regulatory Acceptance	0.00	0.00	0
	Part 3 - Environmental	0.00	0.00	0
	Part 3 - Economics	0.00	0.00	0
	Part 3 - Social Acceptance	0.00	0.00	0
	Part 3 - Technical Feasibility	0.30	0.52	52
	Part 3 - Regulatory Acceptance	0.00	0.00	0
GP 7	Part 1	0.40	0.36	36
	Part 2 - Environmental	0.00	0.00	0
	Part 2 - Economics	1.03	1.14	114
	Part 2 - Social Acceptance	0.15	0.27	27
	Part 2 - Technical Feasibility	0.27	0.24	24
	Part 2 - Regulatory Acceptance	0.16	0.27	27
	Part 3 - Environmental	0.15	0.27	27
	Part 3 - Economics	0.15	0.27	27
	Part 3 - Social Acceptance	0.12	0.22	22
	Part 3 - Technical Feasibility	0.15	0.27	27
	Part 3 - Regulatory Acceptance	0.20	0.34	34

Appendix F

Control Chart Evaluation

Control Chart Evaluation

SWA 1

Consistency Index and Consistency Ratio Results

To evaluate the results for the elicitation, the CI and CR were calculated for each pairwise comparison set. Eleven CI and CR values were calculated for participant SWA 1, which are presented in Table 1. All CR values were below the limit of 0.1, except for the CR value for Part 1 which is 0.37.

Table 1 SWA 1 Consistency Index and Consistency Ratio

Evaluation	Consistency Index	Consistency Ratio	Consistency Ratio Percentage
Part 1	0.37	0.33	33
Part 2 - Environmental	0.00	0.00	0
Part 2 - Economics	0.05	0.06	6
Part 2 - Social Acceptance	0.01	0.02	2
Part 2 - Technical Feasibility	0.03	0.03	3
Part 2 - Regulatory Acceptance	0.00	0.00	0
Part 3 - Environmental	0.04	0.07	7
Part 3 - Economics	0.05	0.08	8
Part 3 - Social Acceptance	0.00	0.00	0
Part 3 - Technical Feasibility	0.00	0.01	1
Part 3 - Regulatory Acceptance	0.03	0.05	5

Control Chart Review

The moving average control chart was graphed for stakeholder SWA 1 (Figure 1). The moving average of CI stayed within the standard deviation and near the CI Average. Though there was a high inconsistency in Part 1, SWA 1 improved the CRs during the rest of the elicitation process. It appears that the stakeholder became more comfortable with the process and was able to achieve more consistency in the pairwise comparisons for Parts 2 and 3. Based on review of the CR values and the control chart, SWA 1's results should be retained to calculate stakeholder group consensus.

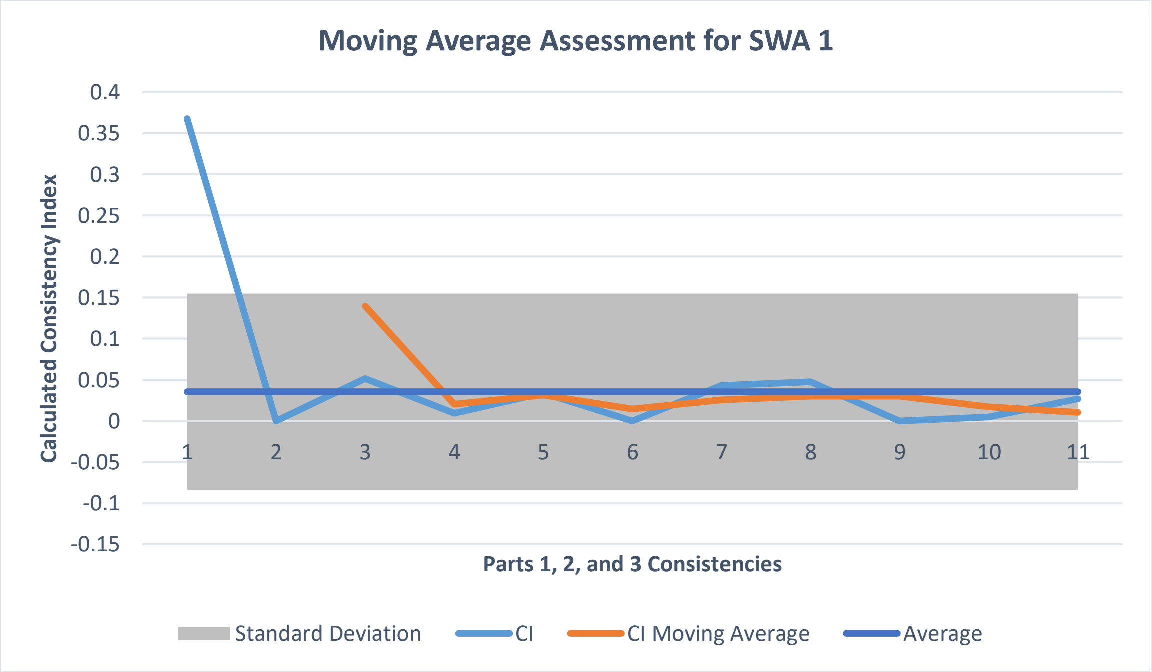


Figure 1 SWA 1 Moving Average Control Chart.

SWA 2

Consistency Index and Consistency Ratio Results

To evaluate the results for the elicitation, the CI and CR were calculated for each pairwise comparison set. Eleven CI and CR values were calculated for participant SWA 2, which are presented in Table 2. All CR values were below the limit of 0.1, except for the CR value for Part 2 and Part 3 for Economics, Social Acceptance.

Table 2 SWA 2 Consistency Index and Consistency Ratio

Evaluation	Consistency Index	Consistency Index	Consistency Ration Percentage
Part 1	0.045	0.040	4
Part 2 - Environmental	0.000	0.000	0
Part 2 - Economics	0.239	0.265	27
Part 2 - Social Acceptance	0.110	0.189	19
Part 2 - Technical Feasibility	0.128	0.115	11
Part 2 - Regulatory Acceptance	0.000	0.000	0
Part 3 - Environmental	0.000	0.000	0
Part 3 - Economics	0.154	0.265	27
Part 3 - Social Acceptance	0.069	0.119	12
Part 3 - Technical Feasibility	0.069	0.120	12
Part 3 - Regulatory Acceptance	0.037	0.064	6

The moving average control chart was graphed for stakeholder SWA 2 (Figure 2). The moving average of CI stayed within the standard deviation and is erratic. Based on the review of the CR values and the control chart, SWA 2's results will not be retained to calculate stakeholder group consensus.

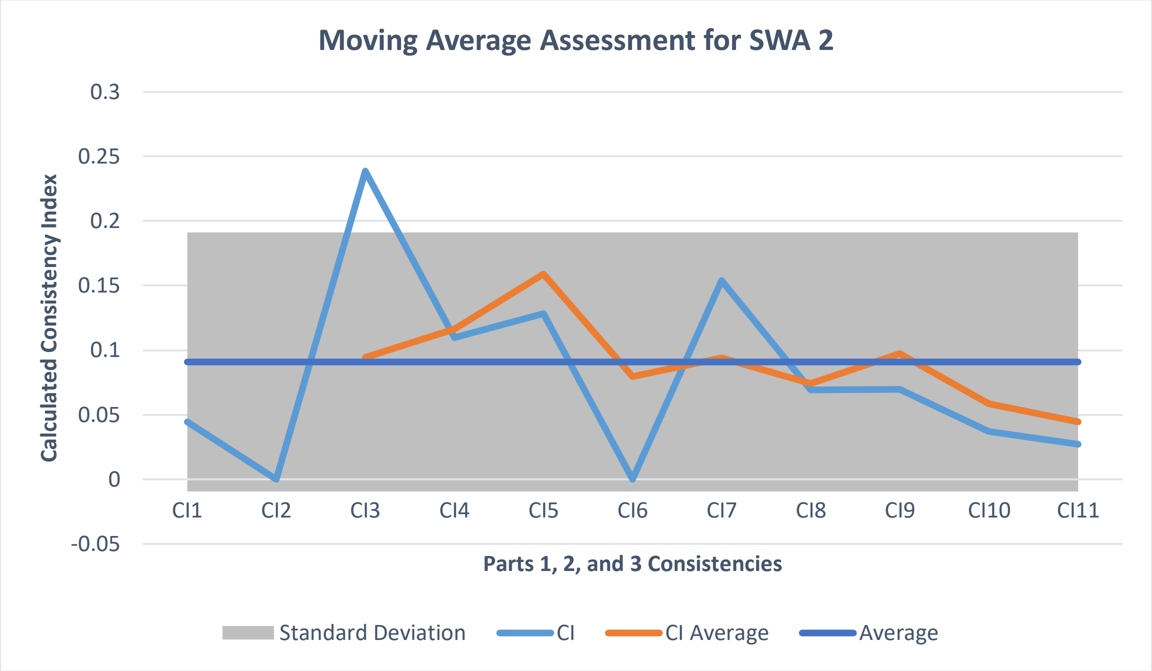


Figure 2 SWA 2 Moving Average Control Chart

SWA 3

Consistency Index and Consistency Ratio Results

To evaluate the results for the elicitation, the CI and CR were calculated for each pairwise comparison set. Eleven CI and CR values were calculated for participant SWA 3, which are presented in Table 3. All CR values were below the limit of 0.1.

Table 3 SWA 3 Consistency Index and Consistency Ratio

Evaluation	Consistency Index	Consistency Ratio	Consistency Ratio Percentage
Part 1	0.060	0.053	5
Part 2 - Environmental	0.000	0.000	0
Part 2 - Economics	0.020	0.023	2
Part 2 - Social Acceptance	0.027	0.046	5
Part 2 - Technical Feasibility	0.034	0.030	3
Part 2 - Regulatory Acceptance	0.027	0.046	5
Part 3 - Environmental	0.000	0.000	0
Part 3 - Economics	0.000	0.000	0
Part 3 - Social Acceptance	0.000	0.000	0
Part 3 - Technical Feasibility	0.000	0.000	0
Part 3 - Regulatory Acceptance	0.027	0.046	5

Control Chart Review

The moving average control chart was graphed for stakeholder SWA 3 (Figure 3). The moving average of CI stayed within the standard deviation and is considered to be in control. The downward motion of the values may indicate that the stakeholder is working hard at becoming more consistency with his pairwise comparisons. Based on the review of the CR values and the control chart, SWA 3's results are retained to calculate stakeholder group consensus.

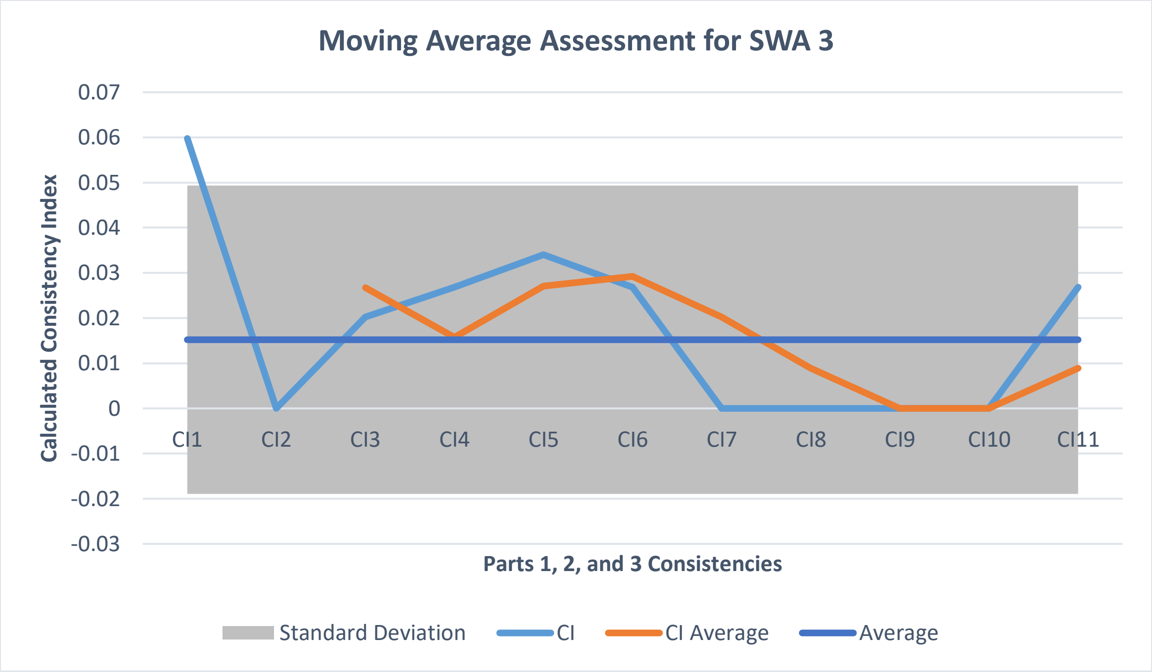


Figure 4 SWA 3 Moving Average Control Chart

CG 1

Consistency Index and Consistency Ratio Results

To evaluate the results for the elicitation, the CI and CR were calculated for each pairwise comparison set. Eleven CI and CR values were calculated for participant CG 1, which are presented in Table 4. The Part 1 Cr was 0.418 or 41.8 percent. The remaining values over 0.1, but less than 0.2, were Part 2 Environmental, Social Acceptance, and Technical Feasibility and Part 3 Technical Feasibility. The remaining CR values were below 0.10.

Table 4 CG 1 Consistency Index and Consistency Ratio

Evaluation	Consistency Index	Consistency Ratio	Consistency Ratio Percentage
Part 1	0.468	0.418	42
Part 2 - Environmental	0.068	0.117	12
Part 2 - Economics	0.000	0.000	0
Part 2 - Social Acceptance	0.069	0.119	12
Part 2 - Technical Feasibility	0.186	0.166	17
Part 2 - Regulatory Acceptance	0.000	0.000	0
Part 3 - Environmental	0.027	0.047	5
Part 3 - Economics	0.147	0.253	25
Part 3 - Social Acceptance	0.009	0.016	2
Part 3 - Technical Feasibility	0.068	0.117	12
Part 3 - Regulatory Acceptance	0.000	0.000	0

Control Chart Review

The moving average control chart was graphed for stakeholder CG 1 (Figure 5). The moving average of CI stayed within the standard deviation and is considered to be in control. Based on the review of the CR values and the control chart, CG 1's results are retained to calculate stakeholder group consensus.

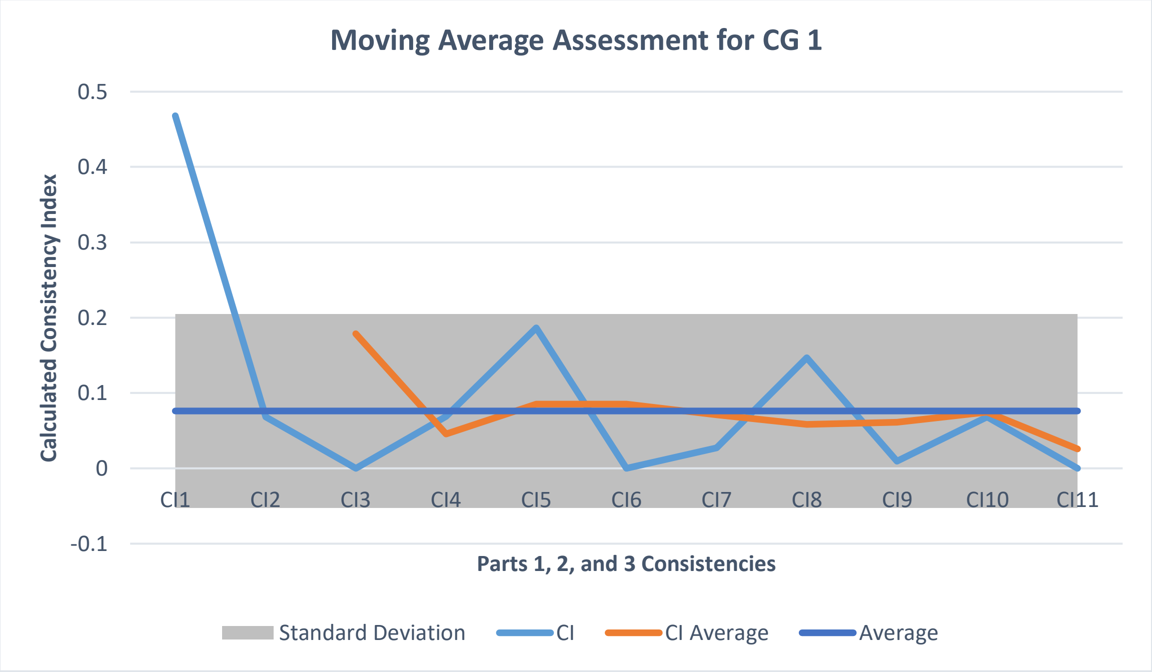


Figure 5 CG 1 Moving Average Control Chart

CG 2

Consistency Index and Consistency Ratio Results

To evaluate the results for the elicitation, the CI and CR were calculated for each pairwise comparison set. Eleven CI and CR values were calculated for participant CG 2, which are presented in Table 5. All CR values were below 0.1 expect for Part 3: Regulatory Acceptance which was calculated to be 0.118, just above the 0.1 limit.

Table 5 CG 2 Consistency Index and Consistency Ratio

Evaluation	Consistency Index	Consistency Ratio	Consistency Ratio Percentage
Part 1	0.100	0.090	9
Part 2 - Environmental	0.000	0.000	0
Part 2 - Economics	0.048	0.054	5
Part 2 - Social Acceptance	0.003	0.005	0
Part 2 - Technical Feasibility	0.044	0.040	4
Part 2 - Regulatory Acceptance	0.009	0.016	2
Part 3 - Environmental	0.001	0.002	0
Part 3 - Economics	0.000	0.000	0
Part 3 - Social Acceptance	0.001	0.002	0
Part 3 - Technical Feasibility	0.000	0.000	0
Part 3 - Regulatory Acceptance	0.069	0.118	12

Control Chart Review

The moving average control chart was graphed for stakeholder CG 2 (Figure 6). The moving average of CI stayed within the standard deviation and the moving average slopes downward. The downward slope of the control chart may be an indication that the stakeholder had tried to answer the pairwise comparisons to meet consistency goals. The CR values are below the 0.1

CR limit, with the exception of Part 3 Regulatory Acceptance. Based on the review of the CR values and the control chart, G 2's results are retained to calculate stakeholder group consensus.

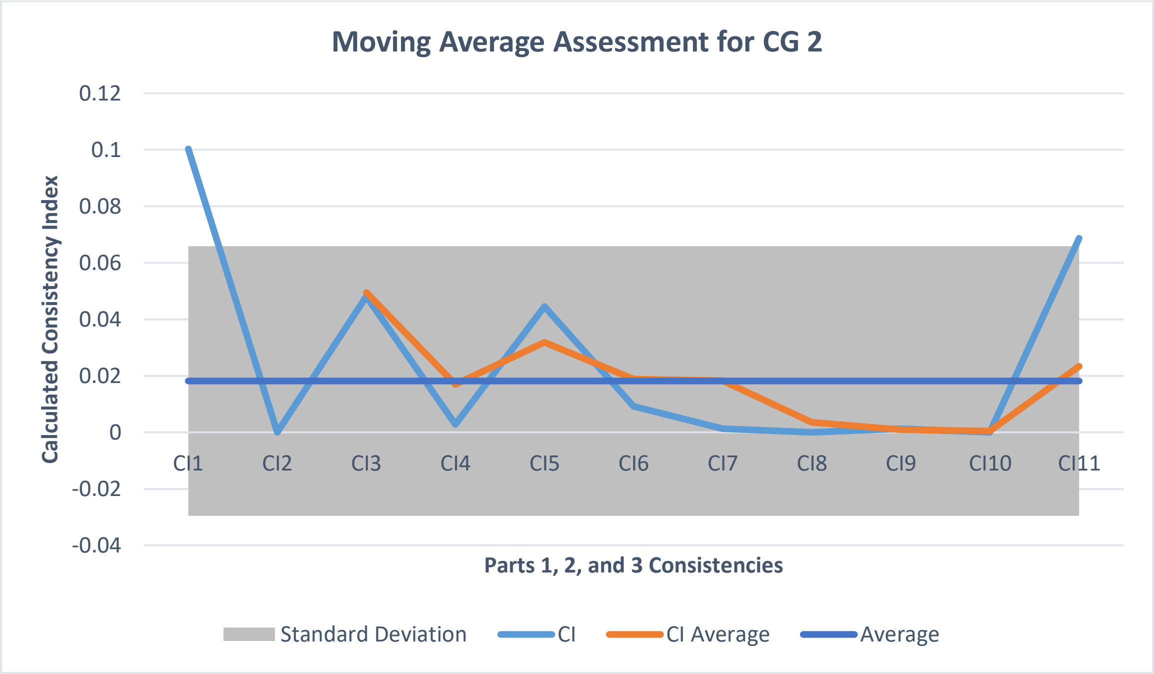


Figure 6 CG 2 Moving Average Control Chart

R 1

Consistency Index and Consistency Ratio Results

To evaluate the results for the elicitation, the CI and CR were calculated for each pairwise comparison set. Eleven CI and CR values were calculated for participant R 1, which are presented in Table 6. All CRs were below 0.1, except for Part 1 and Part 3 Regulatory Acceptance which were slightly above 0.1.

Table 6 R 1 Consistency Index and Consistency Ratio

Evaluation	Consistency Index	Consistency Ratio	Consistency Ratio Percentage
Part 1	0.12	0.11	11
Part 2 - Environmental	0.00	0.00	0
Part 2 - Economics	0.00	0.00	0
Part 2 - Social Acceptance	0.00	0.00	0
Part 2 - Technical Feasibility	0.05	0.04	4
Part 2 - Regulatory Acceptance	0.00	0.00	0
Part 3 - Environmental	0.00	0.00	0
Part 3 - Economics	0.03	0.05	5
Part 3 - Social Acceptance	0.00	0.00	0
Part 3 - Technical Feasibility	0.03	0.05	5
Part 3 - Regulatory Acceptance	0.07	0.12	12

Control Chart Review

The moving average control chart was graphed for stakeholder R 1 (Figure 7). The moving average of CI stayed within the standard deviation and shown slope upwards towards the average line. Based on the review of the CR values and the control chart, R 1's results are retained to calculate stakeholder group consensus.

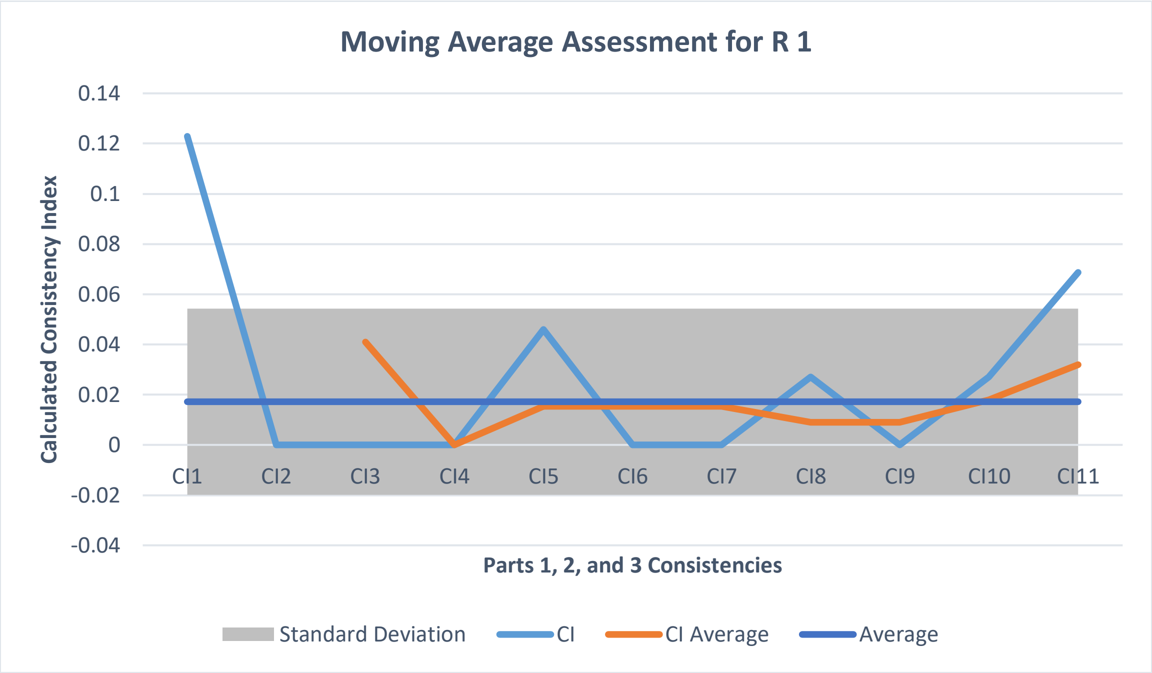


Figure 7 R 1 Moving Average Control Chart

R 2

Consistency Index and Consistency Ratio Results

To evaluate the results for the elicitation, the CI and CR were calculated for each pairwise comparison set. Eleven CI and CR values were calculated for participant R 2, which are presented in Table 7. All CRs were between 0.1 and 0.1, except for Part 3 Technical Feasibility and Regulatory Acceptance where were less than 0.1 and Part 2 Environmental and Social Acceptance which were above 0.2.

Table 7 R 2 Consistency Index and Consistency Ratio

Evaluation	Consistency Index	Consistency Ratio	Consistency Ratio Percentage
Part 1	0.14	0.12	12
Part 2 - Environmental	0.16	0.27	27
Part 2 - Economics	0.11	0.13	13
Part 2 - Social Acceptance	0.45	0.77	77
Part 2 - Technical Feasibility	0.16	0.14	14
Part 2 - Regulatory Acceptance	0.07	0.12	12
Part 3 - Environmental	0.07	0.12	12
Part 3 - Economics	0.07	0.12	12
Part 3 - Social Acceptance	0.07	0.12	12
Part 3 - Technical Feasibility	0.04	0.07	7
Part 3 - Regulatory Acceptance	0.00	0.01	1

Control Chart Review

The moving average control chart was graphed for stakeholder R 2 (Figure 8). The moving average of CI stayed within the standard deviation and shown slope downward below the average line. The CR value for Part 2 Social Acceptance is high and may be an error in the judgement of the stakeholder’s pairwise comparison. Though many of the CRs are greater than

0.1, they are less than 0.2. Based on the review of the CR values and the control chart, R 2's results are retained to calculate stakeholder group consensus.

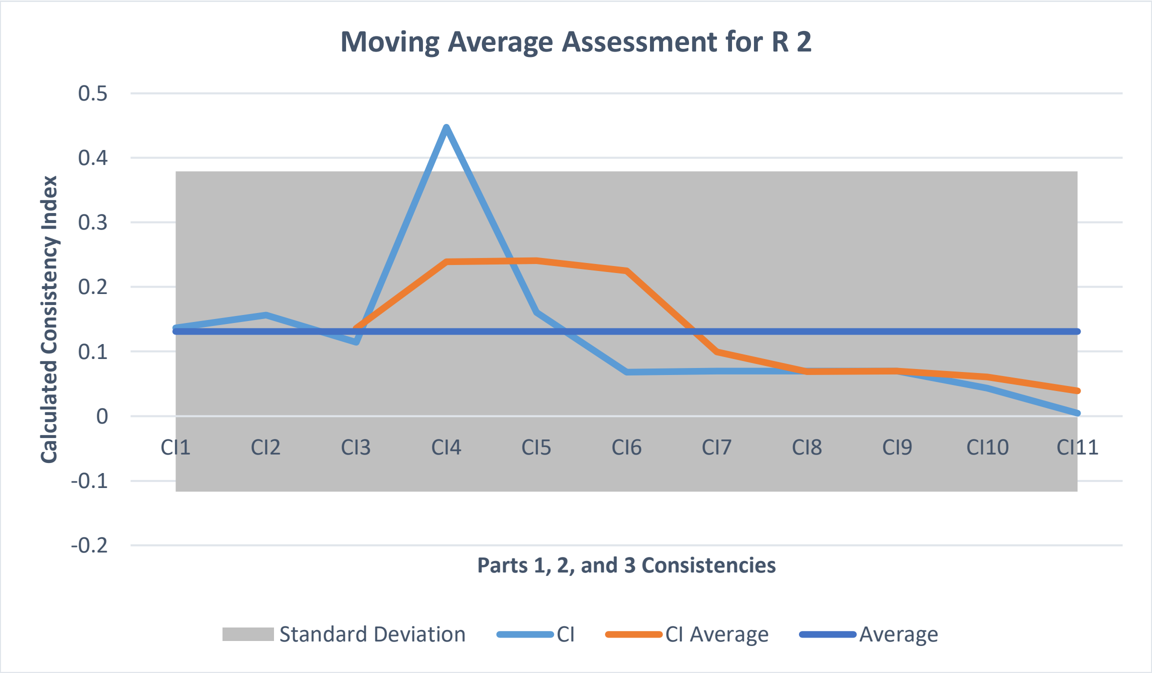


Figure 8 R 2 Moving Average Control Chart

R 4

Consistency Index and Consistency Ratio Results

To evaluate the results for the elicitation, the CI and CR were calculated for each pairwise comparison set. Eleven CI and CR values were calculated for participant R 4, which are presented in Table 8. All CRs were less than 0.2, except for CRs for Part 3 Economics, Social Acceptance, Technical Feasibility, and Regulatory Acceptance were between 0.1 and 0.2.

Table 8 R 4 Consistency Index and Consistency Ratio

Evaluation	Consistency Index	Consistency Ratio	Consistency Ratio Percentage
Part 1	0.04	0.03	3
Part 2 - Environmental	0.00	0.00	0
Part 2 - Economics	0.05	0.06	6
Part 2 - Social Acceptance	0.00	0.00	0
Part 2 - Technical Feasibility	0.00	0.00	0
Part 2 - Regulatory Acceptance	0.00	0.00	0
Part 3 - Environmental	0.00	0.00	0
Part 3 - Economics	0.07	0.12	12
Part 3 - Social Acceptance	0.11	0.19	19
Part 3 - Technical Feasibility	0.07	0.12	12
Part 3 - Regulatory Acceptance	0.07	0.12	12

Control Chart Review

The moving average control chart was graphed for stakeholder R 4 (Figure 9). The moving average of CI stayed within the standard deviation and shown sloping upwards above the average line. The stakeholder may be been suffering from fatigue in the completion of the pairwise comparisons. The CR results of Part 3, except for Environmental were above 0.1, but below 0.2. Based on the review of the CR values and the control chart, R 4's results will not retained to calculate stakeholder group consensus.

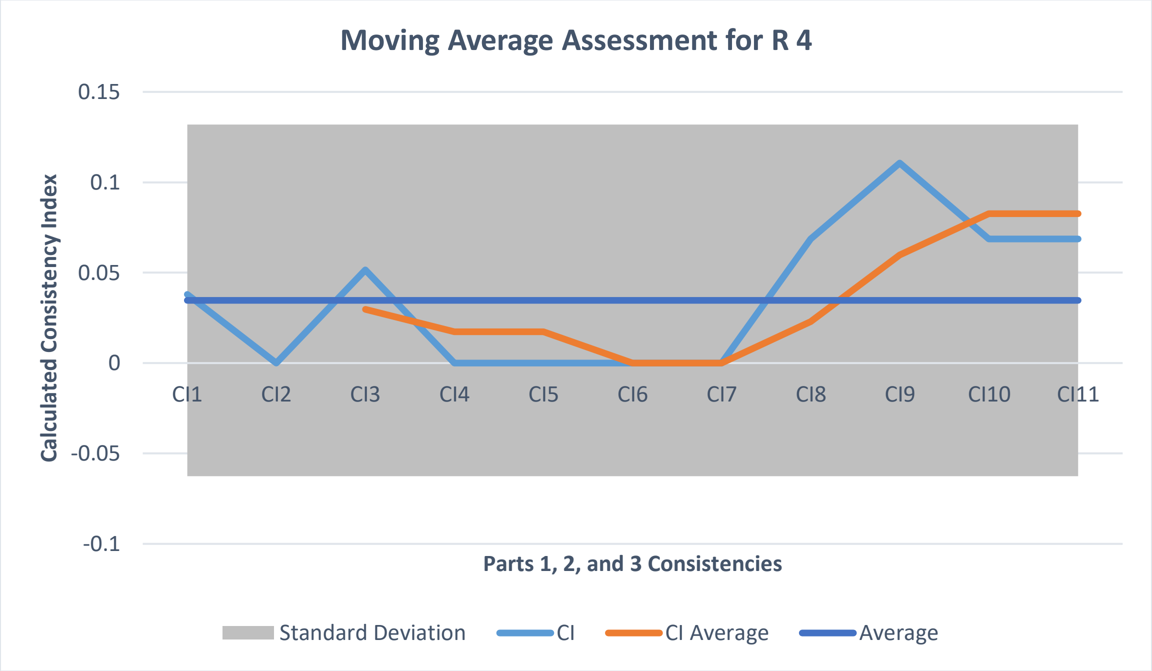


Figure 9 R 4 Moving Average Control Chart

R 6

Consistency Index and Consistency Ratio Results

To evaluate the results for the elicitation, the CI and CR were calculated for each pairwise comparison set. Eleven CI and CR values were calculated for participant R 6, which are presented in Table 9. Only Part 1 had a CRs greater than 0.2. Part 2 Economics, Social Acceptance, and Regulatory Acceptance and Part 3, Environmental and Economics that except for Part 2 Environmental, Part 3 Social Acceptance, and Part 3 Regulatory Acceptance which were below 0.1.

Table 9 R 6 Consistency Index and Consistency Ratio

Evaluation	Consistency Index	Consistency Ratio	Consistency Ratio Percentage
Part 1	0.31	0.28	28
Part 2 - Environmental	0.07	0.12	12
Part 2 - Economics	0.04	0.04	4
Part 2 - Social Acceptance	0.05	0.09	9
Part 2 - Technical Feasibility	0.13	0.12	12
Part 2 - Regulatory Acceptance	0.00	0.00	0
Part 3 - Environmental	0.00	0.00	0
Part 3 - Economics	0.03	0.05	5
Part 3 - Social Acceptance	0.07	0.12	12
Part 3 - Technical Feasibility	0.11	0.19	19
Part 3 - Regulatory Acceptance	0.07	0.12	12

Control Chart Review

The moving average control chart was graphed for stakeholder R 6 (Figure 10). The moving average of CI stayed within the standard deviation and trends up and down around the average line. The Part 1 CR is above 0.2. This high value may be due to the stakeholder becoming familiar with the pairwise comparison process. Based on the review of the CR values and the control chart, R 6's results will not retained to calculate stakeholder group consensus.

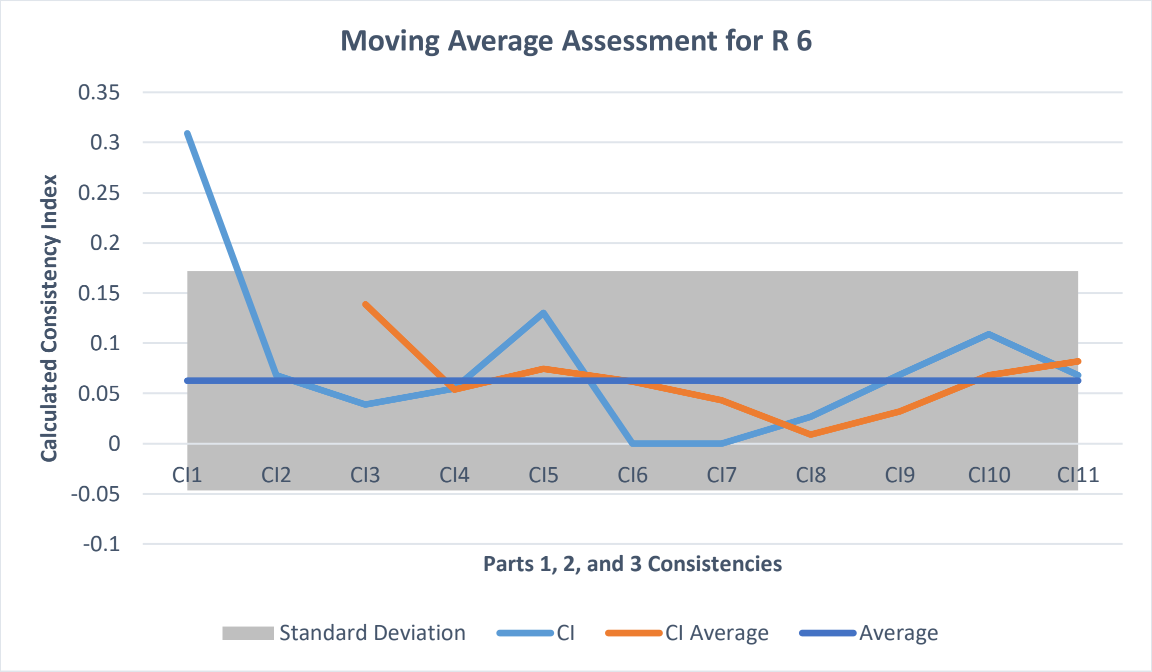


Figure 10 R 6 Moving Average Control Chart

GP 4

Consistency Index and Consistency Ratio Results

To evaluate the results for the elicitation, the CI and CR were calculated for each pairwise comparison set. Eleven CI and CR values were calculated for participant GP 4, which are presented in Table 10. All CR values were greater than 0.1, except for Part 1 which has a CI greater than 0.2 and Part 2 Environmental which has a CR of 0.

Table 10 GP 4 Consistency Index and Consistency Ratio

Evaluation	Consistency Index	Consistency Ratio	Consistency Ratio Percentage
Part 1	0.59	0.53	53
Part 2 - Environmental	0.00	0.00	0
Part 2 - Economics	0.11	0.12	12
Part 2 - Social Acceptance	0.07	0.12	12
Part 2 - Technical Feasibility	0.13	0.11	11
Part 2 - Regulatory Acceptance	0.07	0.12	12
Part 3 - Environmental	0.07	0.12	12
Part 3 - Economics	0.07	0.12	12
Part 3 - Social Acceptance	0.07	0.12	12
Part 3 - Technical Feasibility	0.07	0.12	12
Part 3 - Regulatory Acceptance	0.07	0.12	12

Control Chart Review

The moving average control chart was graphed for stakeholder GP 4 (Figure 11). The moving average of CI stayed within the standard deviation and shown sloping downward then flattening out near the average line. The initial CR is above 0.2 but most of the remaining CR values are just above 0.1. CR values are consistent for the majority of the responses. Based on the review of the CR values and the control chart, GP 4's results are retained to calculate stakeholder group consensus.

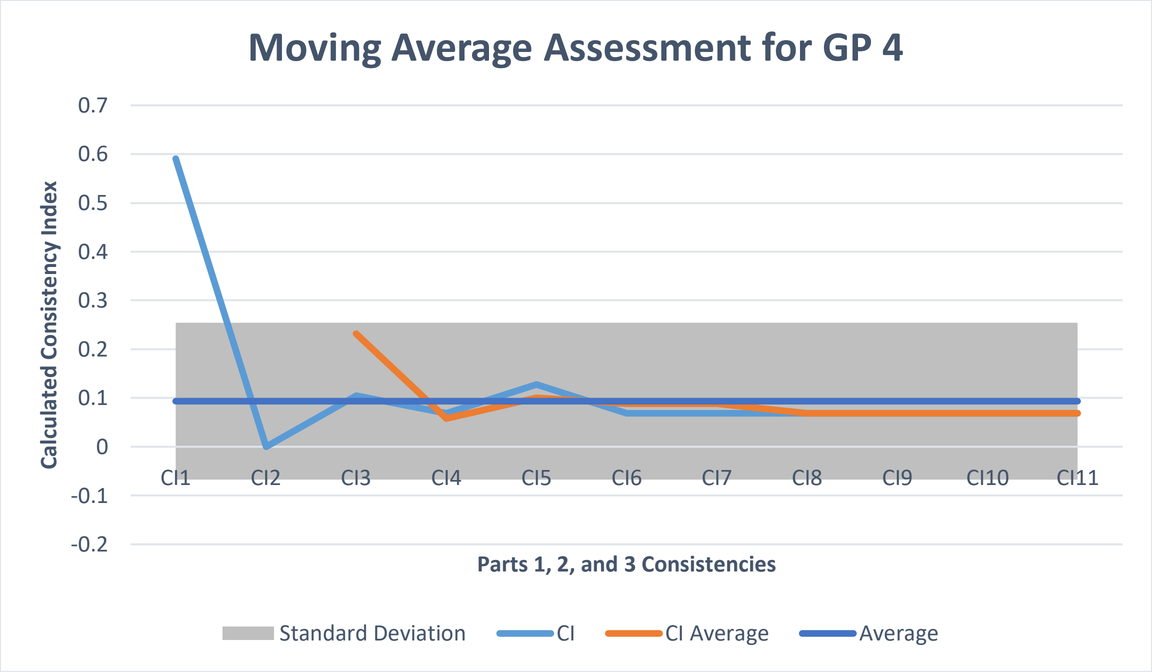


Figure 11 GP 4 Moving Average Control Chart

GP 5

Consistency Index and Consistency Ratio Results

To evaluate the results for the elicitation, the CI and CR were calculated for each pairwise comparison set. Eleven CI and CR values were calculated for participant GP 5, which are presented in Table 11. All CR values were less than 0.1, except for Part 1 (0.16), Part 2 Economics (0.17), and Part 2 Social Acceptance (0.26).

Table 11 GP 5 Consistency Index and Consistency Ratio

Evaluation	Consistency Index	Consistency Ratio	Consistency Ratio Percentage
Part 1	0.18	0.16	16
Part 2 - Environmental	0.00	0.00	0
Part 2 - Economics	0.15	0.17	17
Part 2 - Social Acceptance	0.15	0.26	26
Part 2 - Technical Feasibility	0.00	0.00	0
Part 2 - Regulatory Acceptance	0.00	0.00	0
Part 3 - Environmental	0.00	0.00	0
Part 3 - Economics	0.00	0.00	0
Part 3 - Social Acceptance	0.00	0.00	0
Part 3 - Technical Feasibility	0.00	0.00	0
Part 3 - Regulatory Acceptance	0.00	0.00	0

Control Chart Review

The moving average control chart was graphed for stakeholder GP 5 (Figure 12). The moving average of CI stayed within the standard deviation and shown sloping downward then shown sloping downward and flattening out, almost at the zero axis. The CRs are the same for most of the responses, but the values are much greater than 0.1. Based on the review of the CR values and the control chart, GP 5's results are retained to calculate stakeholder group consensus.

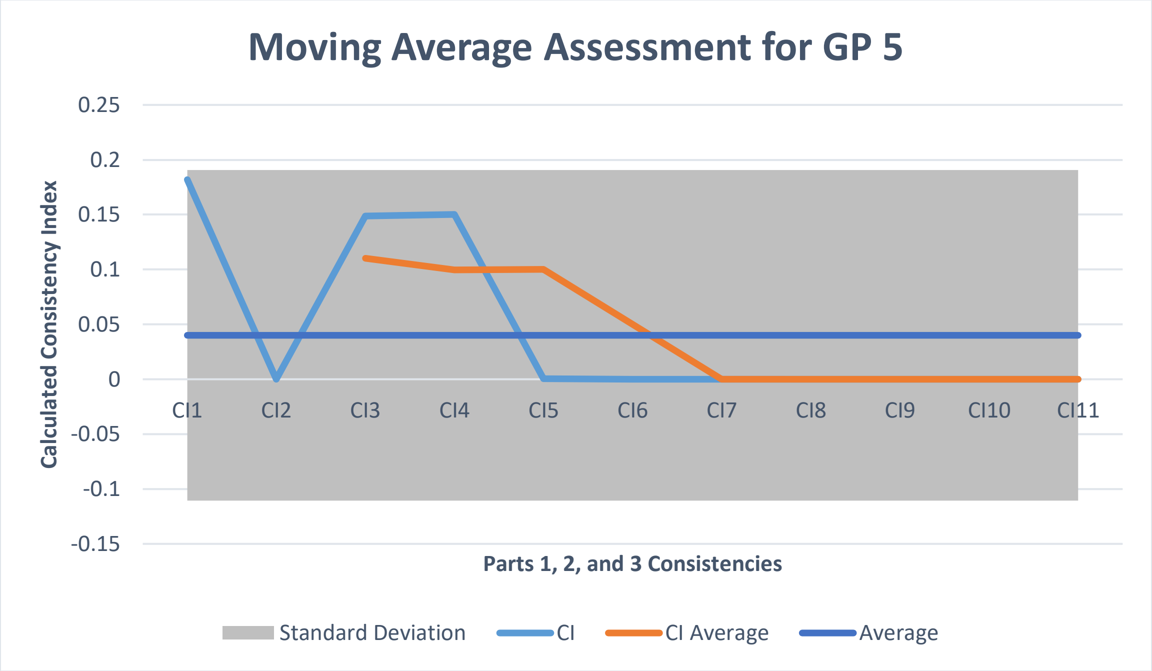


Figure 12 GP 5 Moving Average Control Chart

GP 6

Consistency Index and Consistency Ratio Results

To evaluate the results for the elicitation, the CI and CR were calculated for each pairwise comparison set. Eleven CI and CR values were calculated for participant GP 6, which are presented in Table 12. CR values were less than 0.1, except for Part 1 (0.18), Part 2 Technical Feasibility (0.12), and Part 3 Technical Feasibility (0.52).

Table 12 GP 6 Consistency Index and Consistency Ratio

Evaluation	Consistency Index	Consistency Ratio	Consistency Ratio Percentage
Part 1	0.20	0.18	18
Part 2 - Environmental	0.00	0.00	0
Part 2 - Economics	0.05	0.06	6
Part 2 - Social Acceptance	0.00	0.00	0
Part 2 - Technical Feasibility	0.13	0.12	12
Part 2 - Regulatory Acceptance	0.00	0.00	0
Part 3 - Environmental	0.00	0.00	0
Part 3 - Economics	0.00	0.00	0
Part 3 - Social Acceptance	0.00	0.00	0
Part 3 - Technical Feasibility	0.30	0.52	52
Part 3 - Regulatory Acceptance	0.00	0.00	0

Control Chart Review

The moving average control chart was graphed for stakeholder GP 6 (Figure 13). The moving average of CI stayed within the standard deviation and shown starting near the average line but sloping up and down around the average. The CRs are the same for most of the responses, but there is a high CR for Part 3 Technical Feasibility. This CR is an anomaly when compared with the other CR vales before it and directly after it. This may be due to a lack of understanding of this criterion in relation to the three alternatives. Based on the review of the CR values and the control chart, GP 6's results will not retained to calculate stakeholder group consensus.

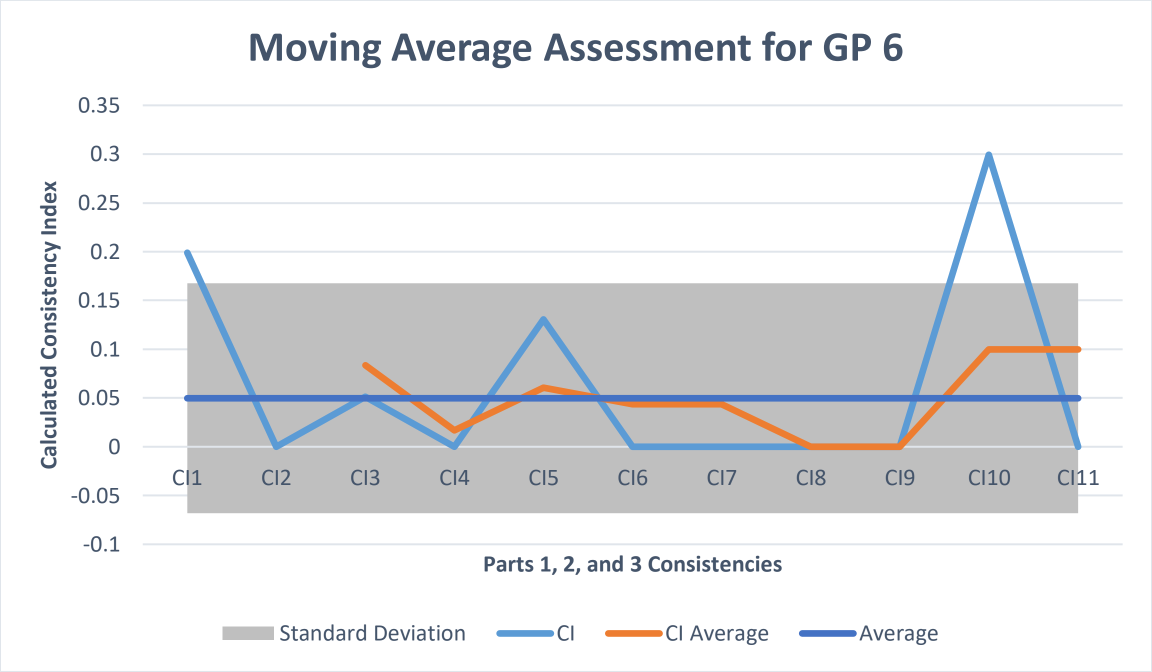


Figure 13 GP 6 Moving Average Control Chart

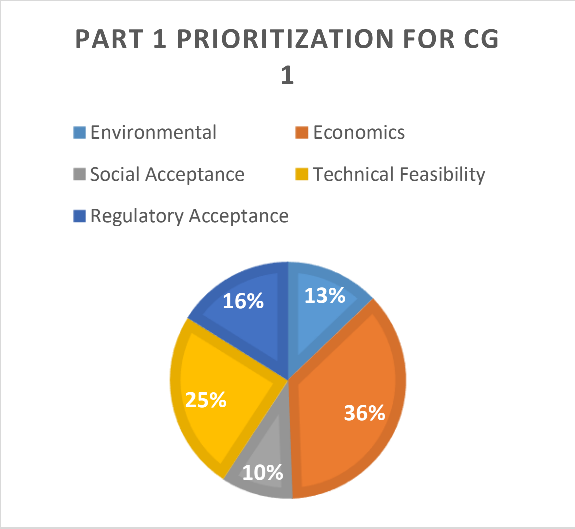
Appendix G

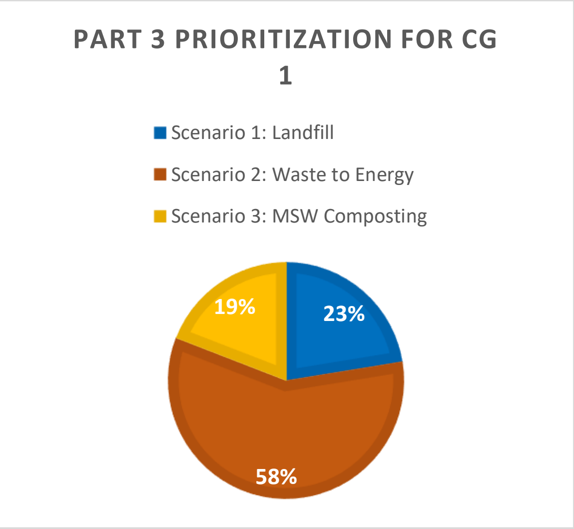
Follow Up Interview Comments from DecisionTogether$^{©}$ Elicitation

Responses to Follow Up Questionnaire

CG1

CG 1 was retained for final evaluation.





CR::

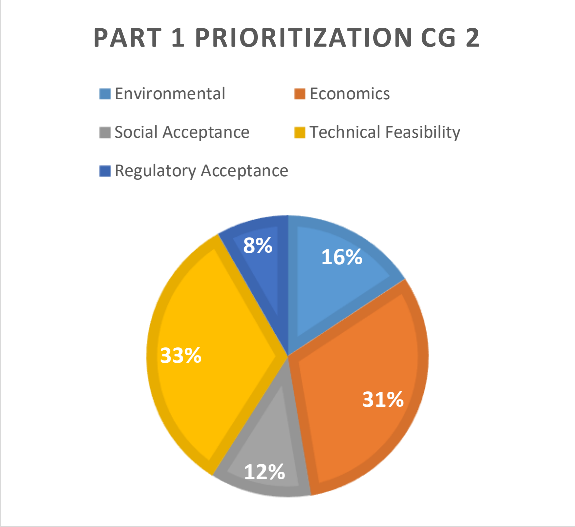
	CI	CR	CR Percent
Q1	0.468	0.418	42
Q2	0.068	0.117	12
Q3	0.000	0.000	0
Q4	0.069	0.119	12
Q5	0.186	0.166	17
Q6	0.000	0.000	0
Q7	0.027	0.047	5
Q8	0.147	0.253	25
Q9	0.009	0.016	2
Q10	0.068	0.117	12
Q11	0.000	0.000	0

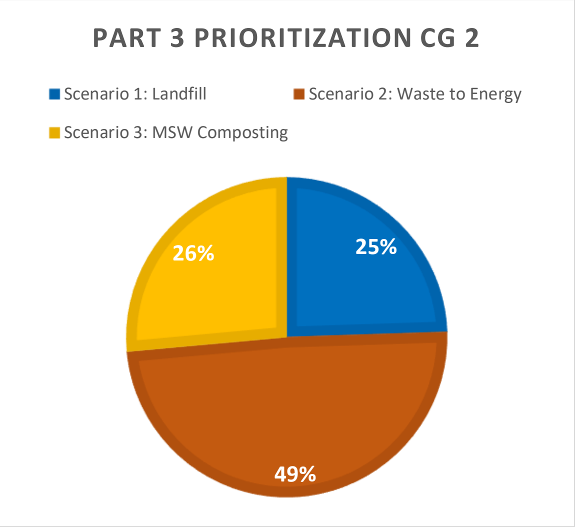
Response to Questionnaire:

I have reviewed the graphs, and they match the answers to previous questions.

CG 2

CG 1 was retained for final evaluation.


PART 1 PRIORITIZATION CG 2


PART 3 PRIORITIZATION CG 2

CR:

	CI	CR	CR Percentage
Q1	0.100	0.090	9
Q2	0.000	0.000	0
Q3	0.048	0.054	5
Q4	0.003	0.005	0
Q5	0.044	0.040	4
Q6	0.009	0.016	2
Q7	0.001	0.002	0
Q8	0.000	0.000	0
Q9	0.001	0.002	0
Q10	0.000	0.000	0
Q11	0.069	0.118	12

1. Do you feel that the priorities presented in the pie charts best represents your preferences and how you think/feel about the criteria, attributes, and alternatives for assessment future municipal solid waste systems?

Yes

2. What factors shaped the answers you provide in the elicitation?

   Experience and feedback from elected officials and the public.

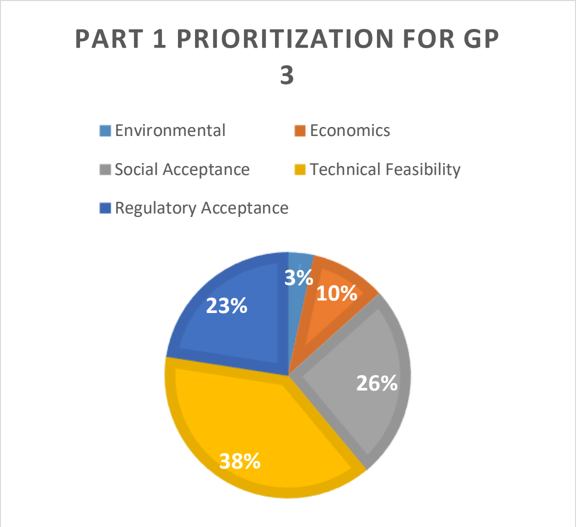
3. What challenges and benefits do you see to these choices?

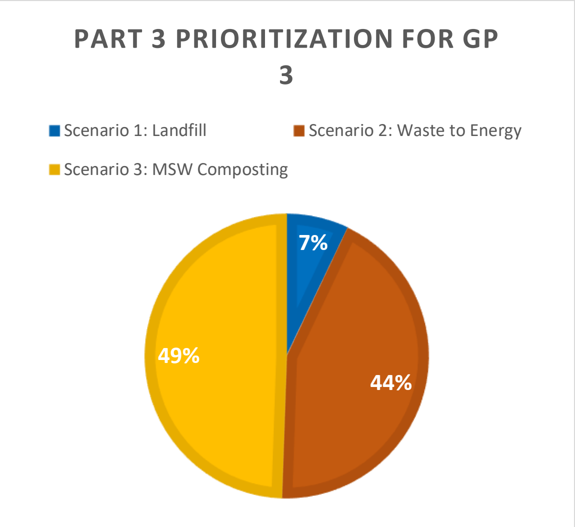
   Biggest challenges are the economics of the relatively new technologies and technical feasibility of the solutions

4. What do you think it would take to convince others of your prioritization?

   Solid examples where successful solutions have been deployed in similar situations.

GP 3
GP 3 was not retained for final evaluation.





	CI	CR	CR Percentage
Q1	0.29	0.26	26
Q2	0.19	0.33	33
Q3	0.28	0.31	31
Q4	0.47	0.81	81
Q5	0.92	0.82	82
Q6	0.33	0.57	57
Q7	0.20	0.35	35
Q8	0.23	0.40	40
Q9	0.20	0.34	34
Q10	0.19	0.32	32
Q11	0.23	0.40	40

1. Do you feel that the priorities presented in the pie charts best represents your preferences and how you think/feel about the criteria, attributes, and alternatives for assessment future municipal solid waste systems?

   Yes, solutions must be real world applicable and all aspects in balance. While weighting of factors are naturally dependent on the biases of the responder, this is good way to represent the factors.

2. What factors shaped the answers you provide in the elicitation?

Waste is inevitable and while an ideal solution would have no negative consequences, respondents must see that all factors, even if unpopular muse be addressed.

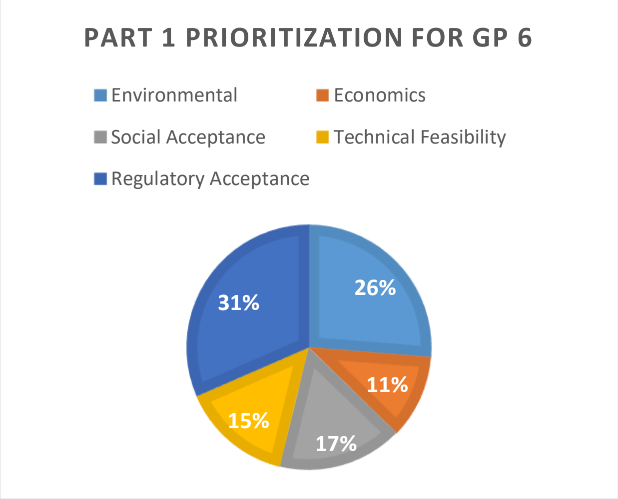
3. What challenges and benefits do you see to these choices?

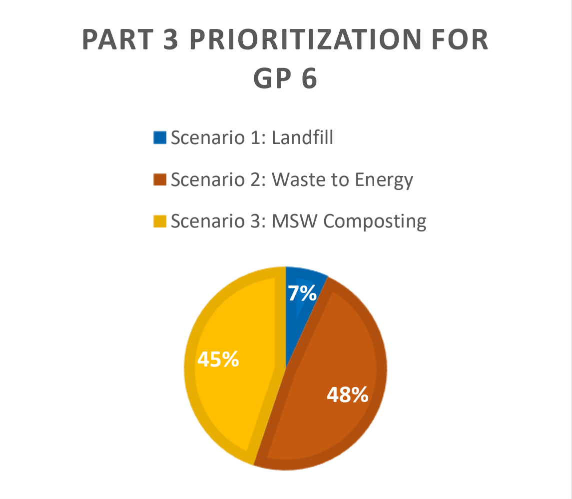
   Few civilians would understand the aspects such as regulatory approval which must be taken into account. The pie chart allows understanding that all factors must be considered and by adding the responses of various persons, especially if possible, in a real time dynamic way such as in a public session would see that balance must be achieved.

4. What do you think it would take to convince others of your prioritization?
   In an open discussion the pie chart shows the attempt to understand that you cannot just ignore that you wish to avoid as a factor. Visual displays are far easier to understand as you show others how each factor takes up its share of the 'pie'.

GP 6

GP 6 was not retained for final prioritization.





CR:

Q1	0.20	0.18	18
Q2	0.00	0.00	0
Q3	0.05	0.06	6
Q4	0.00	0.00	0
Q5	0.13	0.12	12
Q6	0.00	0.00	0
Q7	0.00	0.00	0
Q8	0.00	0.00	0
Q9	0.00	0.00	0
Q10	0.30	0.52	52
Q11	0.00	0.00	0

1. Do you feel that the priorities presented in the pie charts best represents your preferences and how you think/feel about the criteria, attributes, and alternatives for assessment future municipal solid waste systems?

   Part 1: More or less yes. This is in part because as an employee of a regulatory agency employee I understand the regulatory framework and care deeply for environment. I do think environment and regulatory acceptance is good. For social acceptance, I try to be empathetic and aware of it but it doesn't drive my decision. Tech and econ are not a big priority.

Part 3: Yes. I don't know as much about waste to energy, but have faith in emerging technologies. I bought a Prius (car) to support emerging technologies. Waste to energy has promise but we need to know more about the technology and what it can do. I have more experience with composting, I think it needs to be a balanced solution. Think that in actuality landfilling will need to be better and aspire to be more like the other alternatives.

2. What factors shaped the answers you provide in the elicitation?

   Factors include working for a regulatory agency gives more respect and access to the importance for the regulatory aspects. I tried to wear lots of hats while completing the elicitation. Commitment to environment and protecting the resources was most important. Other criteria were secondary. Any It has to be technically feasible for the economics to be low enough to implement. Social acceptance is the greyest area but very important.

3. What challenges and benefits do you see to these choices?

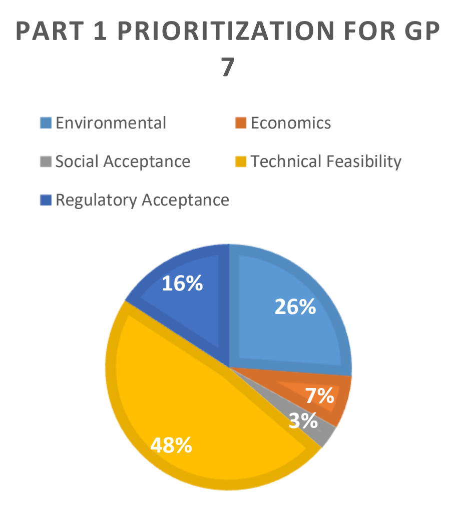
   Challenge: I did not have the technical knowledge to feel that I could provide an educated response on some of the questions. It was hard to know how to answer technical info.

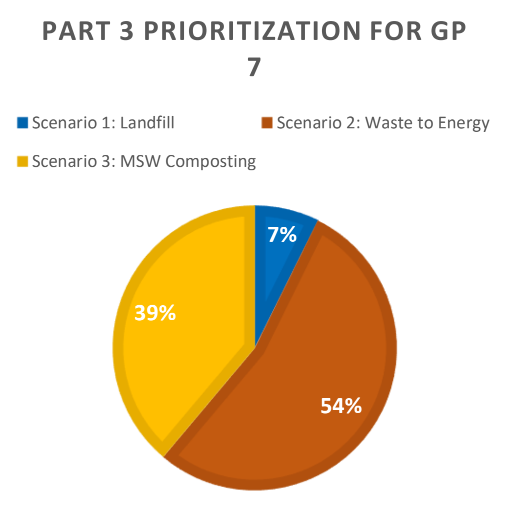
   Benefits: When you can see them all together, you are forced to see all the aspects you might not have compared in other ways,

4. What do you think it would take to convince others of your prioritization?

   Regulatory framework is important because it creates the framework to abide by in implementation. No matter where this solution goes, the regulations provide a good level of protection of environment and provides for a responsible solution, regardless of technology. The regulatory framework is important for public health.
   As for environment, there is urgency to solve environmental problems. There is a moral imperative that we are responsible for the resources we have. We have to be flexible to how to fix this, but at the end of the day, the resources need to be maintained. We have a limited time to make improvements to then environment, so there is sense of urgency. This is a big and nebulous issue that needs to be handle.

GP 7


PART 1 PRIORITIZATION FOR GP 7


PART 3 PRIORITIZATION FOR GP 7

1. Do you feel that the priorities presented in the pie charts best represents your preferences and how you think/feel about the criteria, attributes, and alternatives for assessment future municipal solid waste systems?

   Yes.

2. What factors shaped the answers you provide in the elicitation?

   Land fill itself is environmentally toxic. It removes arable land from cultivation, especially now in this era of climate change. Food sources are shifting. I am a firm believer in recycling. The best way in my opinion to reduce waste is to develop more ways to compost, recycle and covert materials into energy.

   .

   Americans waste is the result of “convenience”. Outside the US, people are more in tune with recycling and composting as a part of personal and national pride by collecting and separating waste.

3. What challenges and benefits do you see to these choices?

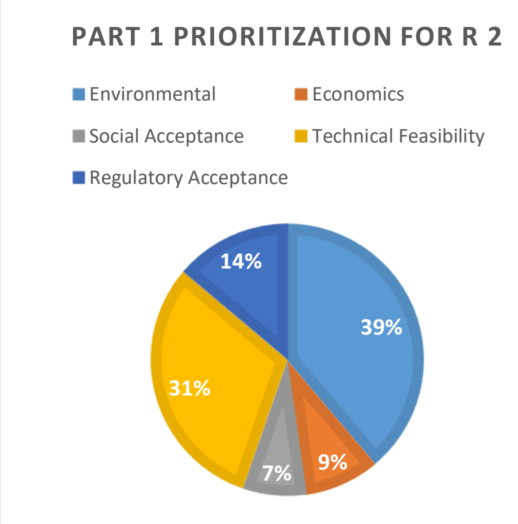
   Governments tend to go for the cheapest way of handling waste, not always the more creative, sustainable way. Also governments do not spend enough effort in educating the people of the benefits of recycling.

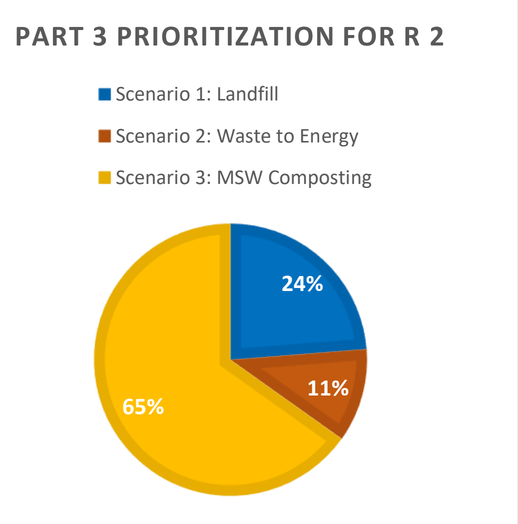
4. What do you think it would take to convince others of your prioritization?

   Cost Benefit Analysis, New Federal Regulations, TV, Phone Apps, Education –

R 2

R 2 was kept for final prioritization.





CR results:

Q1	0.14	0.12	12
Q2	0.16	0.27	27
Q3	0.11	0.13	13
Q4	0.45	0.77	77
Q5	0.16	0.14	14
Q6	0.07	0.12	12
Q7	0.07	0.12	12
Q8	0.07	0.12	12
Q9	0.07	0.12	12
Q10	0.04	0.07	7
Q11	0.00	0.01	1

1. Do you feel that the priorities presented in the pie charts best represents your preferences and how you think/feel about the criteria, attributes, and alternatives for assessment future municipal solid waste systems?

   Yes the ranking does match up.

2. What factors shaped the answers you provide in the elicitation?

   Majority of the factors is from experience in the field and dealing with the stakeholders. I see the problems and potential solutions that are out there. I think that compostable materials is the biggest problems in the landfill and it would be the best to treat outside of the landfill.

3. What challenges and benefits do you see to these choices?

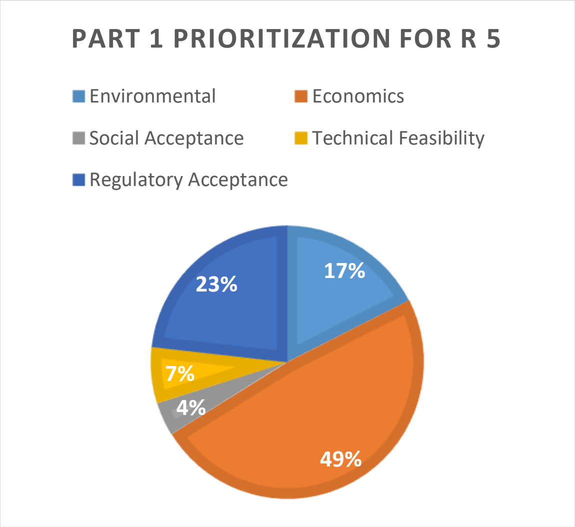
   The primary challenge is to rethink from a collection and management standpoint and how to deal with organics management, how we separate materials and the logistics of getting it treated. Political issues are very important with recovered materials. Lots of political problems. Politicians leaving office changes the programs and staffing that remain after the election.

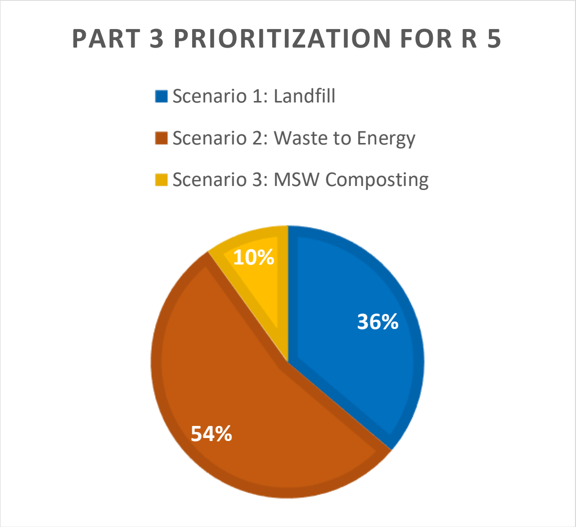
4. What do you think it would take to convince others of your prioritization?

   I think it would require people to get more interested and knowledgeable on the chemistry and mechanisms in the landfill. They don't understand the back end problems that the organics make on the systems. Management at the end of life is based on generation of gas and leachate.

R5

R 5 was not retained for final prioritization.





CR:

	CI	CR	CR Percent
Q1	0.22	0.20	20
Q2	0.04	0.07	7
Q3	0.25	0.28	28
Q4	0.12	0.21	21
Q5	0.25	0.22	22
Q6	0.11	0.19	19
Q7	0.23	0.40	40
Q8	0.16	0.27	27
Q9	0.03	0.06	6
Q10	0.15	0.27	27
Q11	0.00	0.00	0

1. Do you feel that the priorities presented in the pie charts best represents your preferences and how you think/feel about the criteria, attributes, and alternatives for assessment future municipal solid waste systems?

   The priorities fit. Technical feasibility was lower, because it is a moving target. What was acceptable in the past is not acceptable in the future. Everything works no matter what the technical feasibility is. It will evolve as technology evolves. But things will change and catch up.

Waste to energy was the most preferred. But based on review, would have expected waste to energy to rank lower based not being economical.

2. What factors shaped the answers you provide in the elicitation?

   Personal experience. I have worked as a consultant and regulator. I have seen different avenues. Based on my personal perception, we say we hate landfills, but still throw stuff away. I think most people are apathetic, but those who are the most vocal do not represent the population.

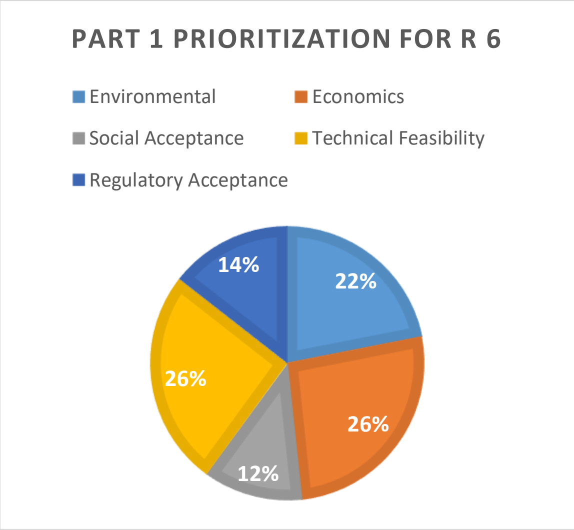
3. What challenges and benefits do you see to these choices?
   N/A

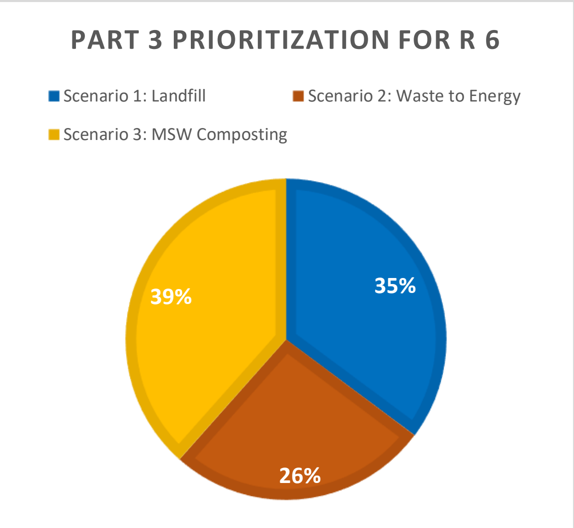
4. What do you think it would take to convince others of your prioritization?

   The success of convincing people is not high, because they have their own perspective and prioritization. Just because I express a prioritization, does not mean they will see it. I support economics and that will dictate the choices. Environmental regulations prevent entities from doing the cheapest thing, but the laws you make will impact the economics of a system. The economics of waste to energy will be more than landfilling. And if you make changes in technologies, the population will be shocked based on the price. Private citizens are controlled by economics. Things are dumped because people do not want to pay for their waste. In a city, the waste bills are buried in another bill and they don't realize they are paying. In rural area, people don't want to pay to dump their waste.

R 6

R 6 was not retained for final prioritization





CR:

	CI	CR	CR Percent
Q1	0.31	0.28	28
Q2	0.07	0.12	12
Q3	0.04	0.04	4
Q4	0.05	0.09	9
Q5	0.13	0.12	12
Q6	0.00	0.00	0
Q7	0.00	0.00	0
Q8	0.03	0.05	5
Q9	0.07	0.12	12
Q10	0.11	0.19	19
Q11	0.07	0.12	12

1. Do you feel that the priorities presented in the pie charts best represents your preferences and how you think/feel about the criteria, attributes, and alternatives for assessment future municipal solid waste systems?

   The three drivers are econ, tech feasibility and regulatory (human health and the environment). But you really need to consider if its economic or technically feasibility. Without these two. it probably won’t get it done. University professors come up with ideas but the ideas work in the lab but are not technically feasible for large scale. Can you scale up to an economical form? Can you take it from bench scale to full scale?

They require so much electricity and infrastructure. Economy of scale is important. Scaling up is a big problem. With today's technology, this is correct. In the future it could work. The economics could change. If gate rate changes (goes up) then they may be able to do more expensive technology. Mass at $98/ton versus $25-30/ton -

2. What factors shaped the answers you provide in the elicitation?

   Experience in the industry and experience as a regulator.

3. What challenges and benefits do you see to these choices?

   Challenges are economics. That is always the case. Convincing people to spend more to do what is the environmentally right thing to do is difficult.

   Benefits: reuse of materials that would normally be thrown away, less environmental impact.

4. What do you think it would take to convince others of your prioritization?

   Public: need to convince them that additional cost is necessary for industry to develop, operate, and maintain the new technology so that we are reusing materials and protecting the environment.

   Industry/Corporate: Need to sell them the soft stuff, they are stewards of the environment and while cost is a driving force, it is not the only force. The large companies with lots of resources both financial and intellectual resources need to take the initiative to develop newer technologies that can implemented in a cost effective manner. Don't just wait for the university professors and researchers that are not in the solid waste industry and do not understand the industry to develop a solution that would be economically feasible. They can do the science. But to scale up, they don't have the skills. Big companies have the resources and money to get the university science and figure out how to get it to an affordable form. Take the initiative.

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